CONTROL OF A BRUSHLESS DC ELECTRIC MOTOR WITH A COMMON ENABLE CONFIGURATION DRIVER

Dotti P.[1], *Poberezkin N. I.*[2]
[1]*TPU, School of Computer Science and Robotics, group 8E11, e-mail: pablo1@tpu.ru*
[2]*TPU, School of Computer Science and Robotics, teaching assistant DAR, e-mail: nip6@tpu.ru*

Abstract

In this paper the working principle of a BLDC motor and how to control it with the six-step and sinusoidal control methods utilizing a common enable configuration driver is addressed. To compare the two different driving methos the current waveform of one of the three phases was analyzed.

Keywords: BLDC motor, sinusoidal control, six-step control, common enable configuration.

Introduction

Brushless DC (BLDC) motors have emerged as a significant technological advancement in the field of electric motors. With their efficient and reliable performance, BLDC motors have gained considerable attention in various industries and applications. In contrast to traditional brushed DC motors, BLDC motors offer several advantages, including higher efficiency, improved power density, enhanced speed control, and longer lifespan due to the absence of mechanical brushes, so they don't have any mechanical wear and tear. These features make BLDC motors an ideal choice for numerous applications, such as electric vehicles, robotics, aerospace systems, industrial automation, and more. Understanding the underlying principles, design considerations, and control strategies of BLDC motors is crucial for maximizing their performance and unlocking their full potential. In this paper, it will be discussed the control principle of a BLDC motor with a driver that has a common enable configuration.

Working principle of a BLDC motor

BLDC motors are synchronous motors. This means that the magnetic field generated by the stator and the magnetic field generated by the rotor rotate at the same frequency. It is also important to know that this type of motors does not experience "slip" as seen in induction motors. BLDC motors can come in single-phase, two-phase or three-phase configurations. In this paper, it is explained how to drive a 3-phase BLDC motor, which is the most common motor type.

The rotor is the part of the motor that spins. It consists of a chassis that holds permanent magnets that are placed in an alternating poles configuration (north, south, north, south). The number of magnets is always bigger than the number or coils of the stator.

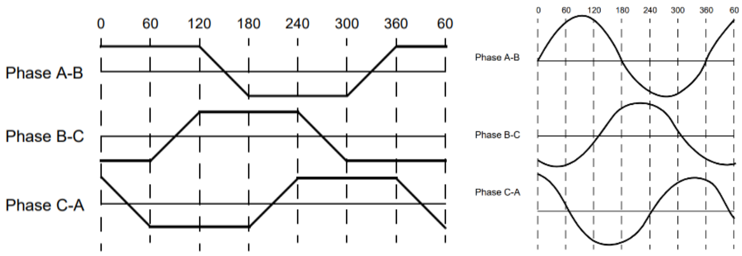
The motor is controlled from the stator, which, as the name implies, is the stationary part of the motor. In the stator, there are 3 different phases that can be connected either in a star or a delta configuration. Each phase is placed 120 degrees from the others, thus forming some sort of equilateral triangle, where each phase is, from the center, pointing to one of the vertices of the triangle. When one phase is turned on, the magnetic field of the stator is pointing, from the center, to the direction of the phase. If two phases are turned on, the magnetic field will point to the center point of the vertices of the two turned on phases. This results in the magnetic field of the rotor spinning only 60 degrees from the original position. So, by turning on and off the 3 phases at the right time, or in a synchronous manner, the magnetic field of the stator will spin, and with it, the rotor [1–3].

BLDC controller

To turn the different phases on and off a controller is used. Controllers are usually composed of a 3-phase inverter. This allows each phase to be connected to ground, to the positive supply rail (Vcc from now on) or to be left "floating" (not connected to neither ground or Vcc) independently from the others. There is also another common configuration in which the enable pins of the gates of each phase are connected together, so there is no possibility of leaving a phase floating. This last configuration is called "common enable configuration" and it is the configuration used in this paper.

Driving methods

There are three main controlling methods for BLDC motors. Those are "six-step control", "sinusoidal control" and "field-oriented control (FOC)". In this paper, only the first two methods will be discussed, mainly focusing on the sinusoidal control. Both require a feedback loop of the position of the motor. This can be accomplished either with hall-effect sensors or, as done here, with an absolute magnetic encoder, which also works on the hall-effect principle. The six-step method is shown below in the fig. 1a, and the sinusoidal method in the fig. 1b.



(a) six-step *(b) sinusoidal*

Fig. 1. Driving methods for a BLDC motor [1]

The main difference between these two methods relies on the smoothness of the motor's rotation. While the six-step method is relatively easy to implement, it results in a not so smooth rotation of the motor, having vibrations. This is where the sinusoidal drive method comes into play. Not having steps, but smooth transitions from phase to phase, it can smoothly turn the motor, resulting in less vibrations.

The main problem that came up during the driving stage of the research was the configuration of the controller. In this paper, a main board from a DIY 3-axis gimbal with a STM32F303F8T6 microcontroller and 3 DRV8313 driver ICs is used. Since all of the components are soldered in one board, there is no possible way to change the connections of the pins. This resulted in all the Enable pins of the MOSFETs (pins that turn them on or off) of the drivers connected together to the microcontroller's pin PB10.

To explain why this is a problem, first, it is necessary to understand how a common ESC (electronic speed controller) or BLDC motor controller works. In fig. 2 a usual controller configuration is shown. We can see that to turn on the coil B we turn the gate Q2 on and pull the gate Q6 to ground. This results in the current flowing from coil B to C, and no current flowing through coil A. When a coil is not connected to neither Vcc (V+ in figure 2 or GND, it is called "floating state", so coil A is now "floating". By making one of the phases float we can make the magnetic field of the stator point to the desired direction.

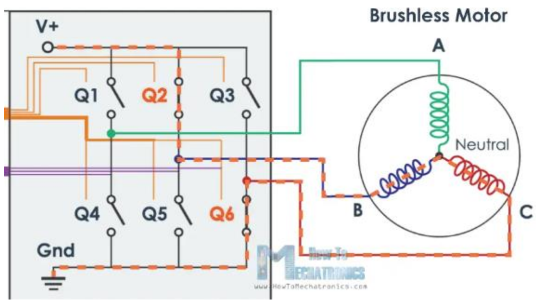


Fig. 2. Working principle of a BLDC driver or ESC [4]

Now that we understand how a common BLDC controller works, we can understand the problem of the common enable configuration. This configuration makes it impossible to leave a phase floating. So, at all times, the phases must be connected to either GND or to Vcc resulting on the magnetic field of the stator pointing not quite to the desired place.

To drive the motor, it was first used the six-step method. With this method the angles for whole revolutions were recorded. As mentioned above, these angles are not consistent, varying from 3 to 7 degrees, resulting in vibrations, high current consumption and low torque. In the process of driving the motor, it was noted that it takes 11 electrical revolutions of the stator magnetic field to achieve one complete mechanical revolution of the rotor. This meant that later on, the revolution in the sinusoidal control would have to be 11 times quicker than the rotor's revolution, so a coefficient was needed.

To start explaining this method, it is easier to express it in 3 formulas (1, 2 and 3), one for each phase:

$$A = \sin(k\alpha + \Delta\alpha), \quad (1)$$

$$B = \sin(k\alpha + 120^{\circ} + \Delta\alpha), \quad (2)$$

$$C = \sin(k\alpha + 240^{\circ} + \Delta\alpha). \quad (3)$$

where *A*, *B*, and *C* are the phases, *k* is the coefficient to match the speed of the rotor (equal to 11 as mentioned above), α is the angle from the feedback loop, and $\Delta\alpha$ is the difference of the magnetic field of the rotor and the magnetic field of the stator. According to the right-hand rule, to get the maximum amount of torque in a motor the rotor magnetic field should be perpendicular to the stator magnetic field. With this in mind the $\Delta\alpha$ coefficient was set to 90 degrees.

With all of the equations and coefficients, the code was written to implement them. To try and solve the common enable problem, the negative part of the sines was deleted, this resulted in a smoother rotational movement of the rotor in comparison to the six-step method. On top of this controlling system 2 regulators were build. The first regulator controls the position. This was done with a P controller (PID wasn't used since the proportional component was enough to achieve acceptable results). Then, a PI controller was used to control the speed. This is because the P controller had a constant error that made the system unusable, so an I (integral) component was added. The current waveform using this method is shown in fig. 3.

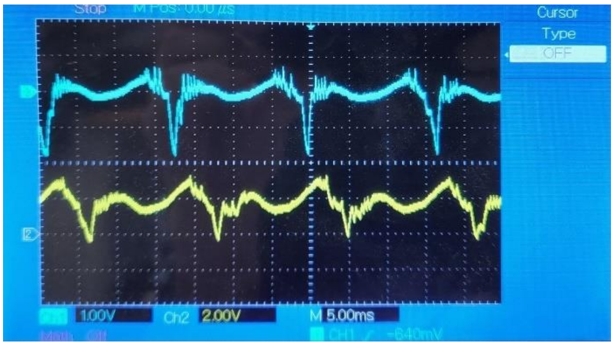
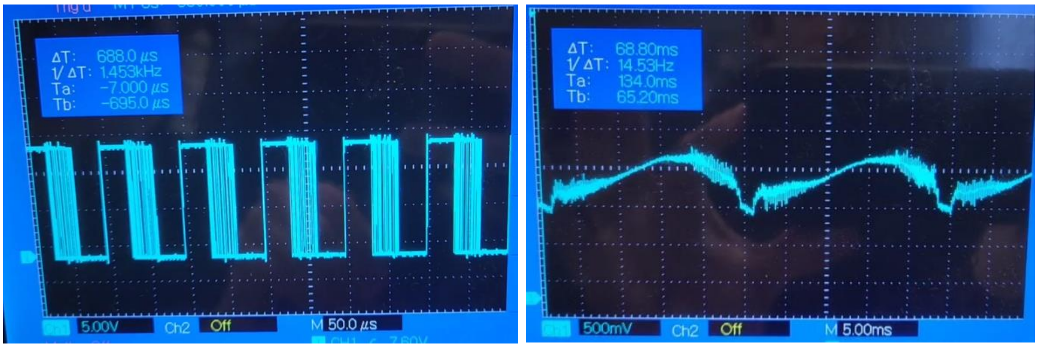


Fig. 3. Current waveforms, where yellow is the current of one phase of the motor

As can be seen in fig. 3, the current waveform is not a sine wave as it should be. This led to high vibrations and noise in the current measurement process. To try and get a better result with the sinusoidal control, one more attempt was made at solving the problem with the common enable configuration. This time, instead of deleting the negative part of the sines, the sines were shifted up by a value equal to their maximum amplitude. This resulted in only positive values and the maximum and minimum of the sines corresponding to the maximum and minimum of the PWM duty cycle value. The PWM output is can be seen in fig. 4a.

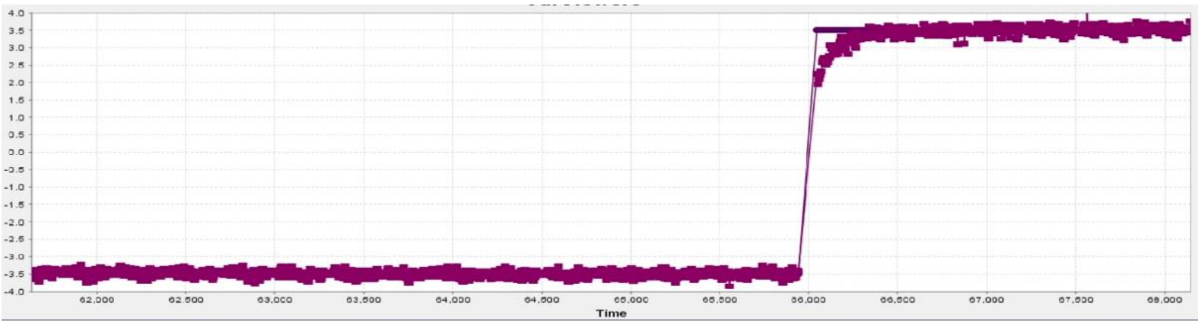
This greatly increased the smoothness of rotation, as well as the current consumption and the waveform of the current. The waveform of the current can be seen in fig. 4b.

As it can be seen in the figure above, the current approximates a sine wave, which is what was expected. Then a 3-contour control system was implemented, with P controller for position, PI for speed, and PI for current. A current control system was implemented to have the possibility to specify the maximum torque of the motor, and to keep the whole system safe. Transient responses from the different regulators are shown in fig. 5.

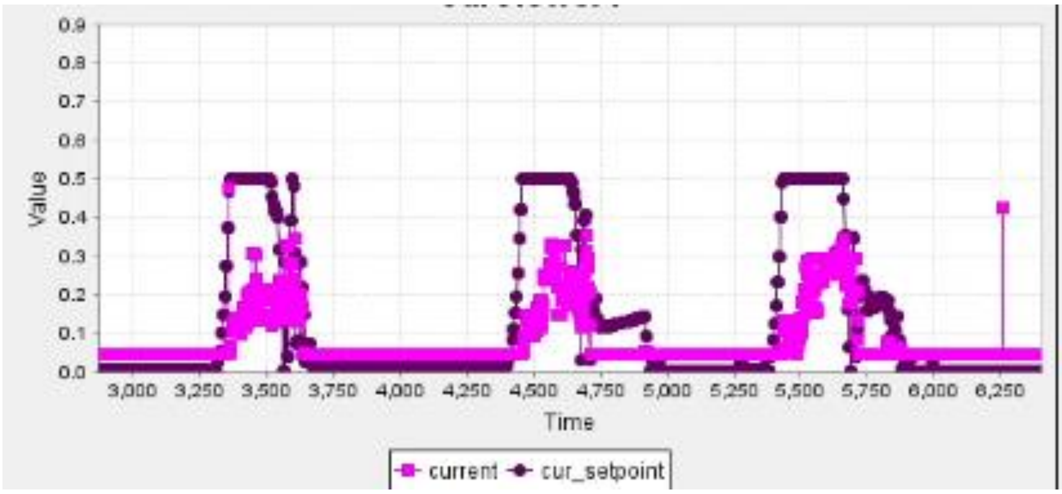


(a) Voltage (b) Current

Fig. 4. The motor's current and voltage waveforms



(a) Speed regulator's transient response



(b) Current regulator's transient response when outside forces applied

Fig. 5. Regulators' transient responses

As can be seen in fig. 5, both regulators do their job quite well. The speed regulator has no overshoot and the current regulator has no problem keeping the current lower than the established limit. This offers full control over the motor while also ensuring its longevity and performance.

Conclusion

BLDC motor control method with a sensed sinusoidal approach with a driver that has a common enable configuration can be done if taken into account the necessary things. These things are the shift that had to be done in the program and the nuisances that arrived to achieve smooth operation. Never the less, this option was explored and implemented. In the future, it is planned to explore the third and last method of BLDC motor driving, field-oriented control, which provides other advantages over sinusoidal drives.

References

1. Brushless DC (BLDC) Motor Fundamentals / Padmaraja Yedamale // ELECTRATHON OF TAMPA BAY
2. Modeling and simulation of the BLDC motor in MATLAB GUI / B. Tibor, V. Fedák and F. Durovský, // 2011 IEEE International Symposium on Industrial Electronics, Gdansk, Poland. – 2011, – pp. 1403-1407
3. Locus diagrams of net magnetic field vector of dual winding induction motor / A.I. Çanakoğlu, M.M. Tezcan, A.G. Yetgin, B. Cevher and M. Turan // International Conference on Electromechanical and Power Systems (SIELMEN), Iasi, Romania, 2017, pp. 108-11, doi: 10.1109/SIELMEN.2017.8123320 – IEEE. – 2017, – pp. 108-11
4. How Brushless DC Motor Works? BLDC and ESC / Dejan // How To Mechatronics – 7.01.2021