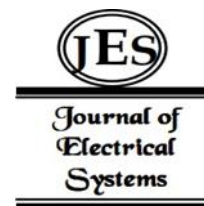


¹ Do Chi Thanh*² Dang Ngoc Huy

Speed Control of BLDC Motor Using PI Controller in MATLAB Simulink



Abstract: - Nowadays, there are more and more variable speed drive systems in small-scale and large-scale applications such as the electric vehicle industry, household appliances, medical equipment and other industrial fields. led to the development of BLDC (Brushless DC) motors. BLDC drive has many advantages such as higher efficiency, better speed torque characteristics, high power density and low maintenance cost compared to other conventional motors. Most BLDC motors use a proportional integral (PI) controller and a pulse width modulation (PWM) scheme for speed control. This article describes the simulation model of BLDC motor drive control with the help of MATLAB - SIMULINK simulation software. The built simulation model includes BLDC motor dynamic block, Hall sensor signal generation block, inverter converter block and PI controller.

Keywords: Brushless DC motor, Brushless DC, Six-step inverte, PI speed, Hall sensor.

I. INTRODUCTION

The use of the general type dc motors has its long history. It has been used in the industries for many years now. They provide simple means and precise way of control [1]. In addition, they have high efficiency and have a high starting torque versus falling speed characteristics which helps high starting torque and helps to prevent sudden load rise [2]. But with such characteristics, the dc motors have some deficiencies that needed to be attended to which gave rise to design of some other alternative types of dc motors. For example, the lack of periodic maintenance, mechanical wear outs, acoustic noise, sparking, brushes effects are some of the problems that were needed to overcome the defects in dc motors. As a result, emphatic studies have been made on synchronous dc motors with brushless commutators. So, current researches have been tailored towards developing brushless direct current motors, which are fast becoming alternatives to the conventional dc motor types. The BrushLess Direct Current (BLDC) motors are gaining grounds in the industries, especially in the areas of appliances production, aeronautics, medicine, consumer and industrial automations and so on. The BLDC are typically permanent synchronous motors, they are well driven by DC voltage. They have a commutation that is done mainly by electronics application. Some of the many advantages of a brushless dc motor over the conventional “brushed dc motors are highlighted below [3], [4]:

1. Better speed versus torque characteristics
2. High dynamic response
3. High efficiency
4. Long operating life
5. Noiseless operation
6. Higher speed ranges
7. Low maintenance (in terms of brushes cleaning; which is peculiar to the brushed DC motors). Another vital advantage is that the ratio of torque delivered to the size of the motor is higher, and this contributes to its usefulness in terms of space and weight consideration.

In fact, these types of motors depend on its control circuit. In fact, these types of motors rely on its control circuit and still developing a high performance circuit is a challenging task for researchers. A basic control system is shown in Fig. 1 for the BLDC motor.

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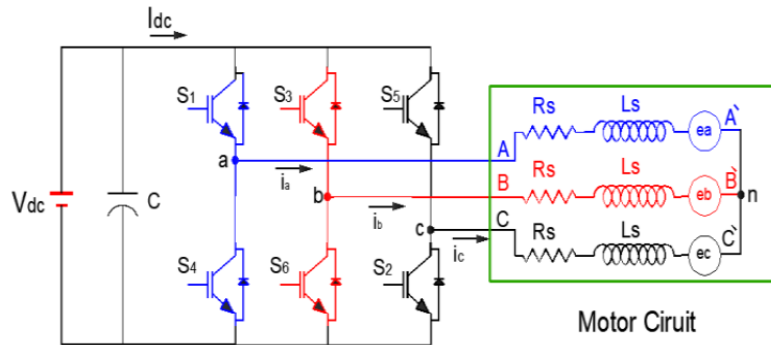


Fig. 1. Basic Circuit Diagram for the BLDC Motor Control System

II. BLDC MOTOR AND SPEED CONTROL SYSTEM

2.1 Speed control system

Figure 2 shows a block diagram of a BLDC motor speed controller using two closed-loop systems. In this case, the inner loop is used to regulate and sense the electrode power and the outer loop is used to control the speed. The motor speed controller helps regulate the DC bus voltage. To control the system, a DC source is required and its value depends on the motor speed (rpm) and its power. This system also requires a controller, in which case a PID controller is used to ultimately control the output voltage of the inverter [8]. A sensor is an integral part of a closed-loop controller control the speed of the motor. Main function of the sensor is to convert the position and physical condition of the motor shaft into an equivalent electrical signal control circuit. Typically, BLDC motors require a controller just like AC. The voltage waveform for its operation should use an inverter circuit to convert the DC power voltage into an AC voltage equivalent to the mains voltage [5], [6] for normal operation.

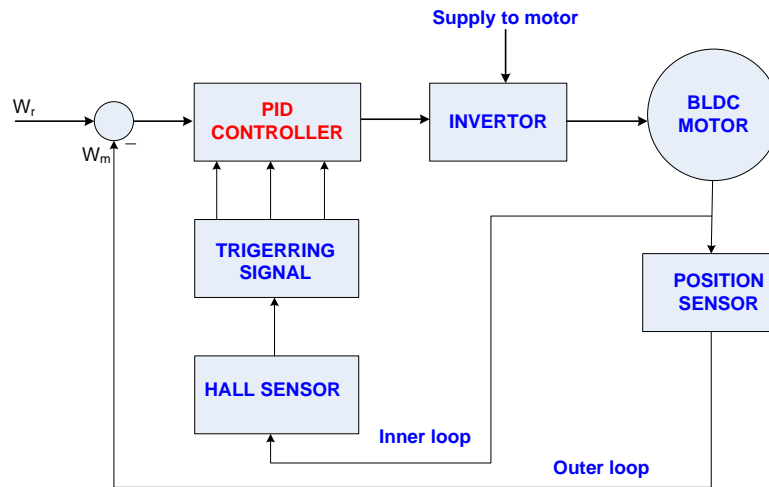


Fig. 2. Block Diagram of BLDC Motor Speed Control.

2.2 The Back Electro Motive Force (BEMF)

Typically, a 3-phase BLDC motor uses six electronic switches (power transistors) to produce 3-phase voltage simultaneously to a full-bridge configuration power converter. The transistors have a rotor position, which will be defined as the switching sequence. Most of the cases motor starter is monitoring by using three hall sensor devices. The hall sensors provide the information to the decoder block for producing the sign of reference current signal vector to the back electromotive force (BEMF). The MATLAB simulation block diagram for generating the back EMF of the decoder is shown in Fig. 3, and Table 1 shows the decoder sequences of the proposed 3-phase PID controller for the BLDC motor to rotate in the clockwise direction.

Table 1: Truth table for generation of EMF_A, EMF_B, EMF_C

Ha	Hb	Hc	EMF_A	EMF_B	EMF_C
0	0	0	0	0	0
0	0	1	0	-1	+1

0	1	0	-1	+1	0
0	1	1	-1	0	+1
1	0	0	+1	0	-1
1	0	1	+1	-1	0
1	1	0	0	+1	-1
1	1	1	0	0	0

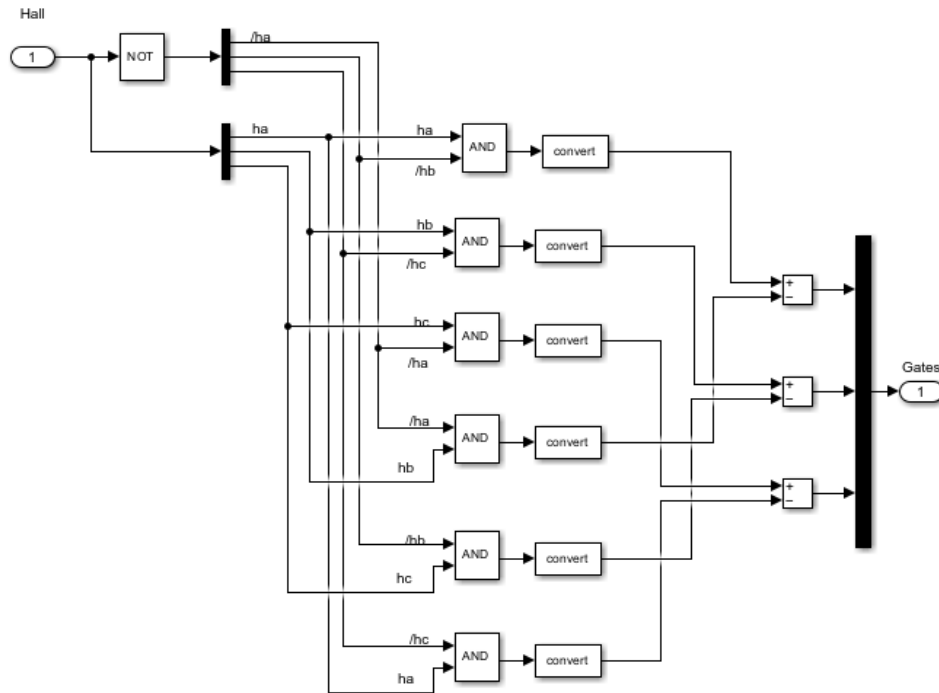


Fig. 3. Back EMF of Decoder for MATLAB Drive.

Similar reasoning we have, Figure 4 shows the functional block diagram of switching of 3-phase inverter for MATLAB simulation and Table 2 shows the decoding sequence of the proposed 3-phase PI controller for a BLDC motor rotating in counter-clockwise direction of motion.

Table II: Tuth table for generation of Pulses for Inverter

EMF_A	EMF_B	EMF_C	Q1 =S1	Q2 =S4	Q3 =S3	Q4 =S6	Q5 =S5	Q6 =S6
0	0	0	0	0	0	0	0	0
0	-1	+1	0	0	0	1	1	0
-1	+1	0	0	1	1	0	0	0
-1	0	+1	0	1	0	0	1	0
+1	0	-1	1	0	0	0	0	1
+1	-1	0	1	0	0	1	0	0
0	+1	-1	0	0	1	0	0	1
0	0	0	0	0	0	0	0	0

For proper operation of a BLDC motor, it is necessary to keep the angle between the stator and rotor flux close to 90 degrees. With six-step control, the motor has a total of six possible stator flux vectors. The stator flux vector must be changed at a certain rotor position. However, with a six-step control technique it is not possible to keep the angle between the rotor flux and the stator flux at 90 degrees. The real angle varies from 60 degrees to 120 degrees [9]. These issues are shown in table 3, figure 5, figure 6.

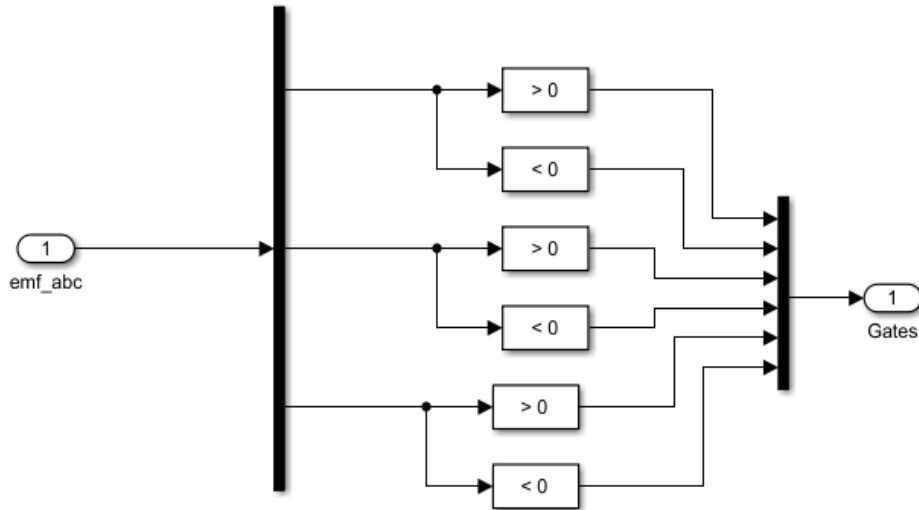


Fig. 4. Inverter Switching for MATLAB Drive

Table III: Generation of Signal for Hall Effect Sensors

θ_{elec}	Ha	Hb	Hc	State
0-60	1	0	0	4
60-120	1	1	0	6
120-180	0	1	0	2
180-240	0	1	1	3
240-300	0	0	1	1
300-360	1	0	1	5

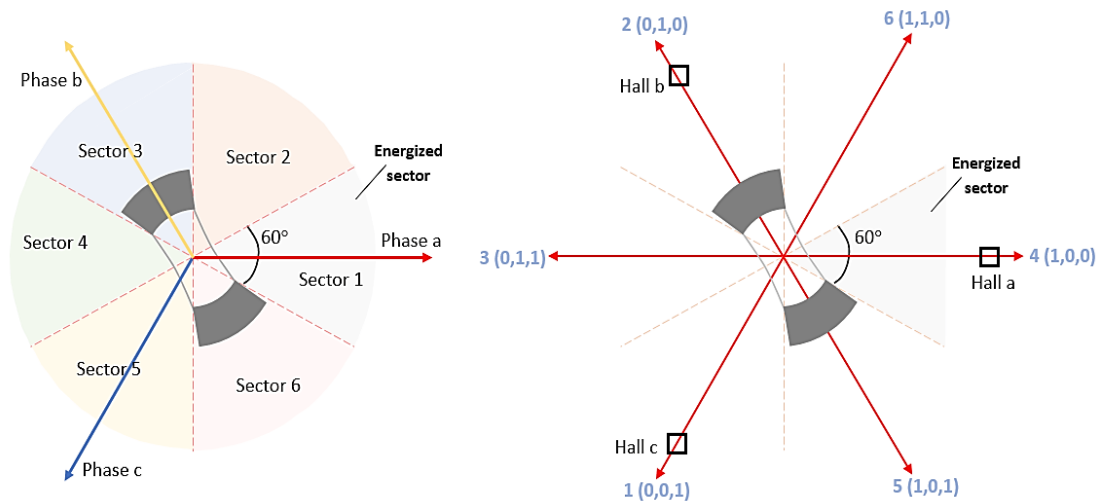


Fig. 5. Six-step commutation process of BLDC motor

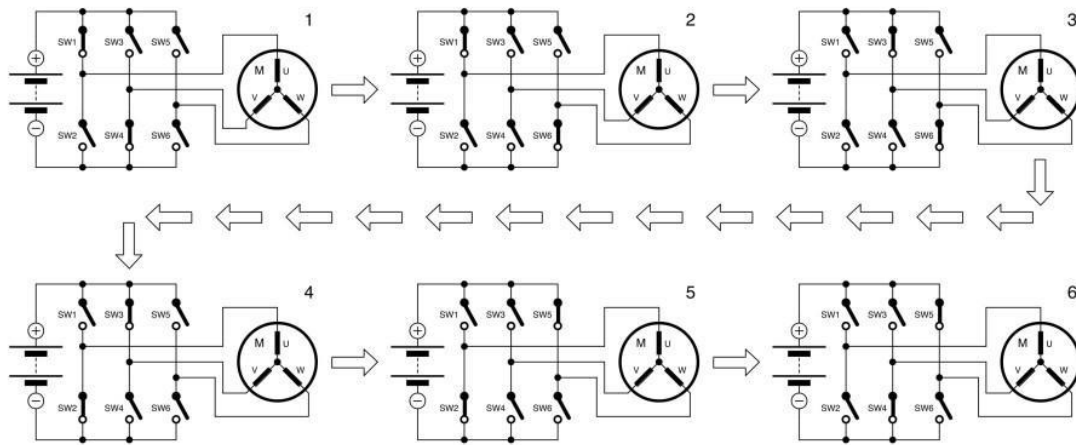


Fig. 6. Simplified circuit diagram showing how the BLDC motor phases are controlled using a three-phase bridge. The switches are typically implemented using MOSFETs or IGBTs.

III. PID CONTROLLER

To improve the performance and more stable speed regulation of the BLDC motor, it is necessary to use a PID controller Figure 7. For this purpose, a variety of control circuits and algorithms are used. PID controller consists of three circuit blocks and they are proportional, integral and derivative blocks. Each circuit block is used to perform different mathematical operations as their name suggests. The complete MATLAB model of the controller is proposed for The 3-phase BLDC motor is shown in Figure 8, 9. Diagram clearly shows how the reference source, PID controller, circuit driver, sensor, converter circuit, inverter circuit, display scope and motor are interconnected.

$$U(t) = K_p e(t) + K_i \int e(t) + K_d \frac{de(t)}{dt} \tag{1}$$

The applications of the PID controller are applied because it is easy and excellent performance, in many cases, its efficiency is more than 95%. Typically, a closed -loop PID controller is used for the application industry. The four main features are most concerned in feedback for the closed round step, they are, the settlement time, excessive, stable state error and response time. Table 4 shows the values of the PI controller parameters used in this article.

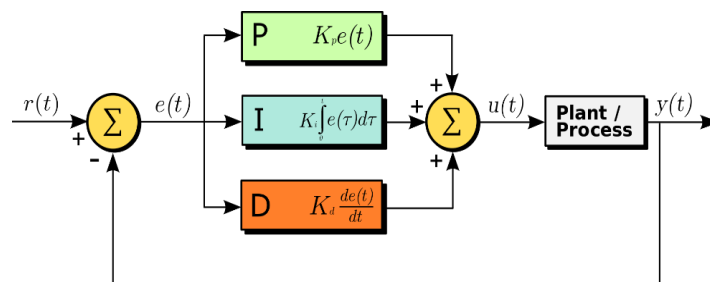


Fig. 7. Schematic of PID controller

Table IV: Values of the PI controller parameters

Method	Values of the PI Controller Parameters	
	KP	KI
PI	0.75	50

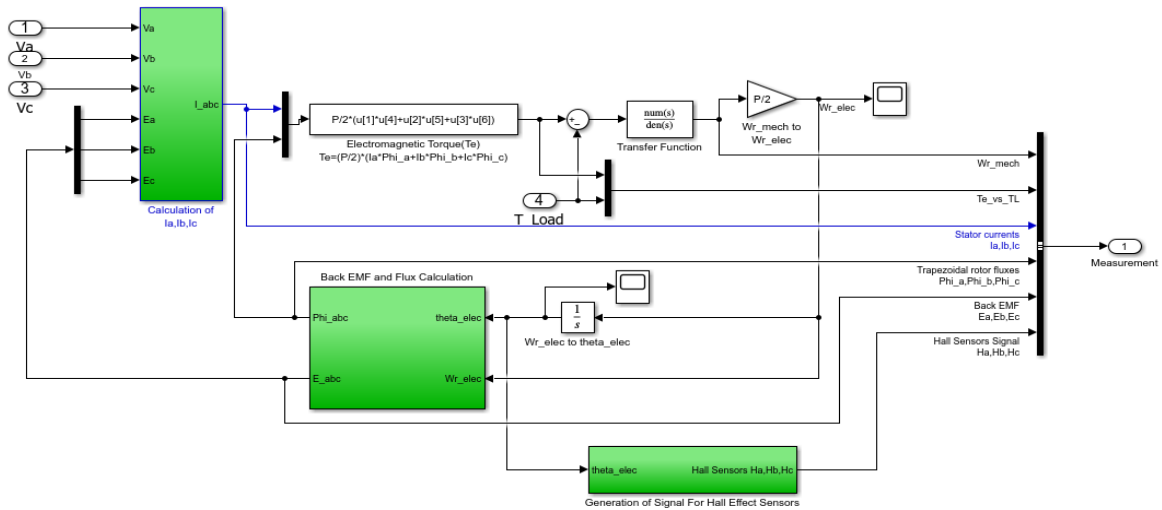


Fig. 8. BLDC motor model in Matlab simulink

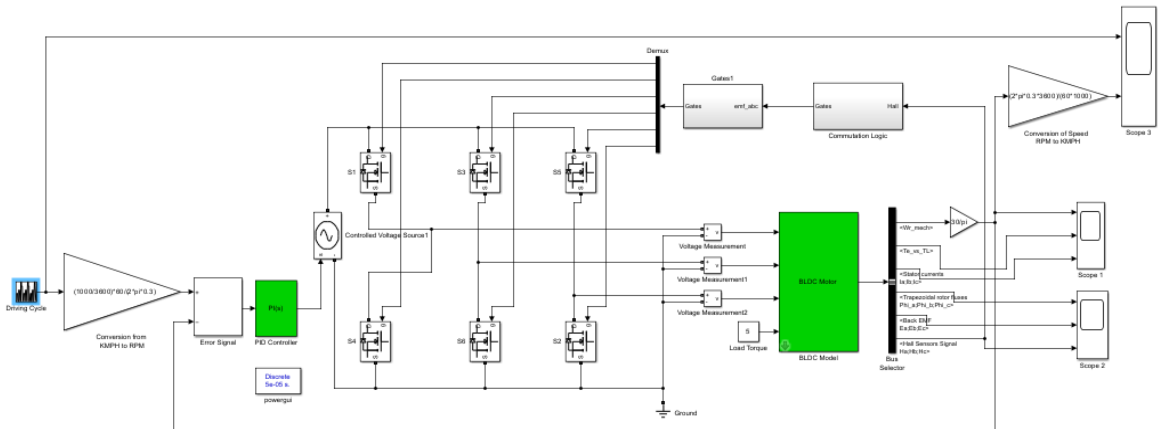


Fig. 9. Matlab Simulink model of Controller for BLDC motor.

IV. MODEL SIMULATION RESULTS

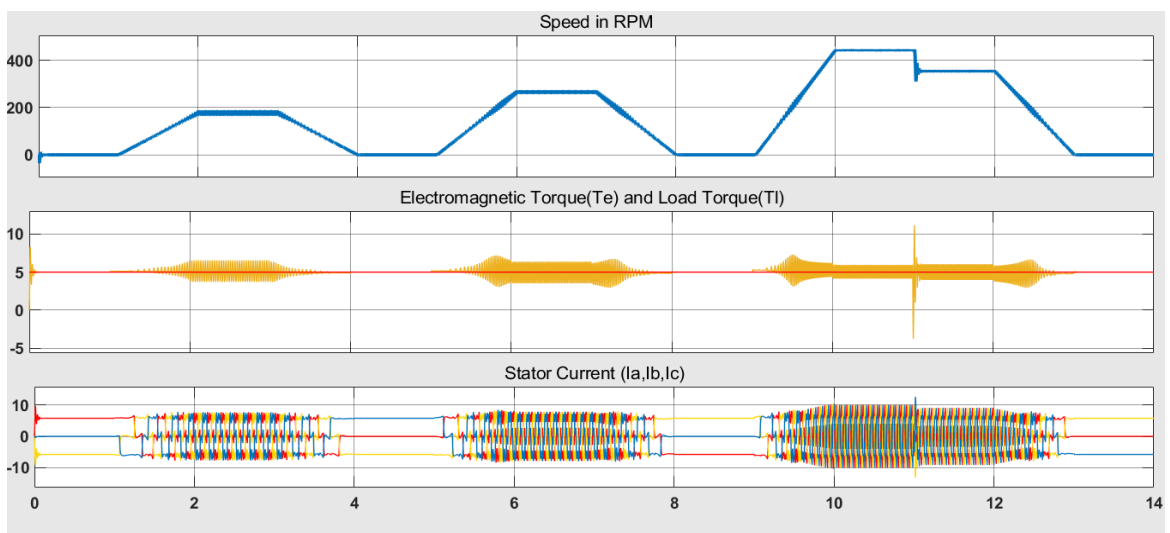


Fig. 10. Simulation results: Speed in RPM, Electromagnetic Torque (Te) and Load Torque (TI), Phase Stator Current of the BLDC Motor

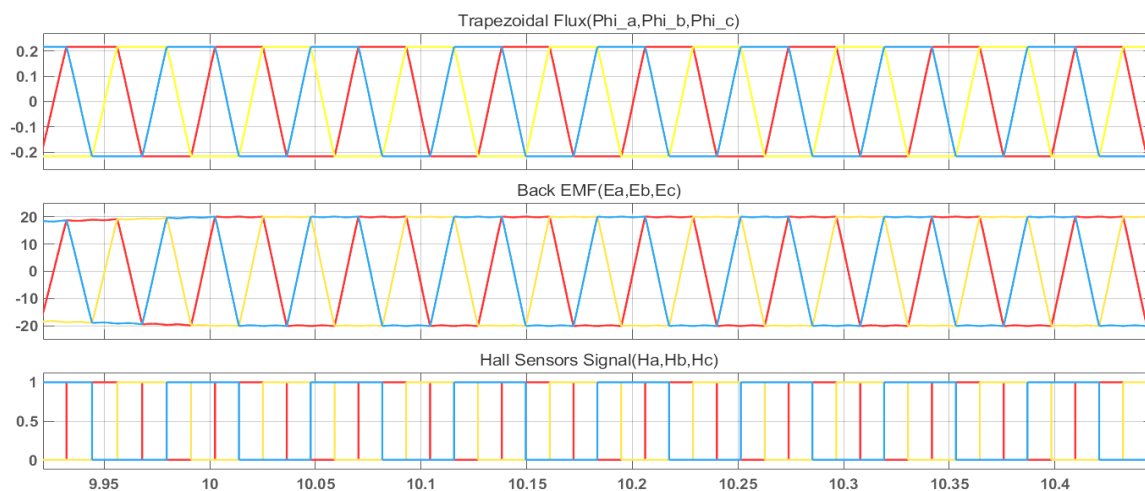


Fig. 11. Simulation results: Trapezoidal Flux Φ_a , Φ_b , Φ_c , BLDC Motor 3-Phase Back Electromotive Force, BLDC Motor Hall Effect Signal

V. DISCUSSION

Simulation results in this paper, a BLDC motor with three-phase inverter has been simulated in 120 degree conduction mode using a Hall sensor. The PI controller is designed and simulated for closed-loop operation of the BLDC motor. Simulation results show that the peak overshoot is reduced when using the PI controller, resulting in speed control achieving the desired results. The simulation of a brushless motor with a Matlab tool - Simulink is done in detail and exactly as with the actual engine model. The results of the article are the basis for surveying and researching the design of the BLDC motor control system the result is the basis for helping to study more deeply about PID controller for BLDC engine.

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