EE6303: ELECTRIC MACHINES II

LABORATORY 03

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REG No. : EG/ 2020/ 4102

SEMESTER: 06

DATE : 25 /10 /2024

Table 1 : Summative laboratory form

Semester	06
Module Code	EE6303
Module Name	Electric Machines II
Lab Number	03
Lab Name	Simulation of Brushless DC Motor
Lab conduction date	2024.10.18
Report Submission date	2024.10.25

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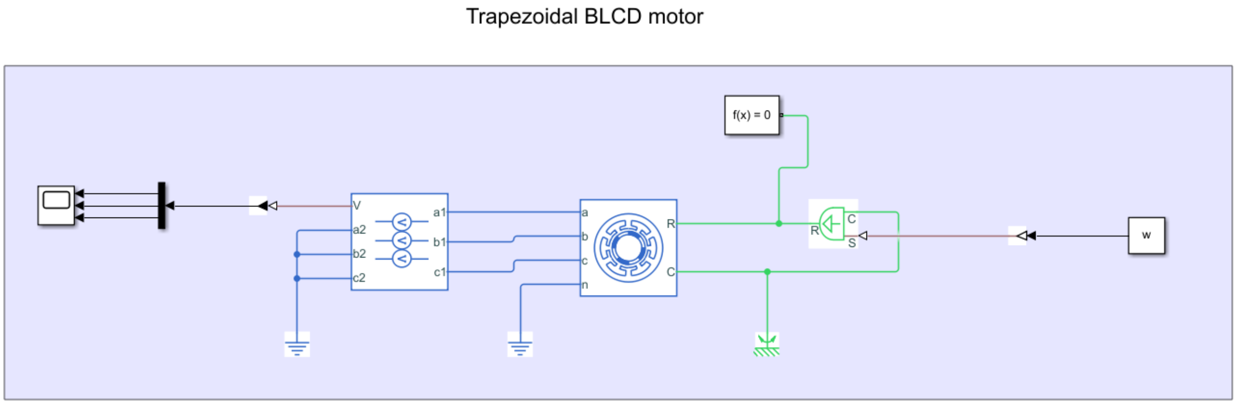

Figure 1 : SIMULINK model for back EMF profile of trapezoidal BLDC motors

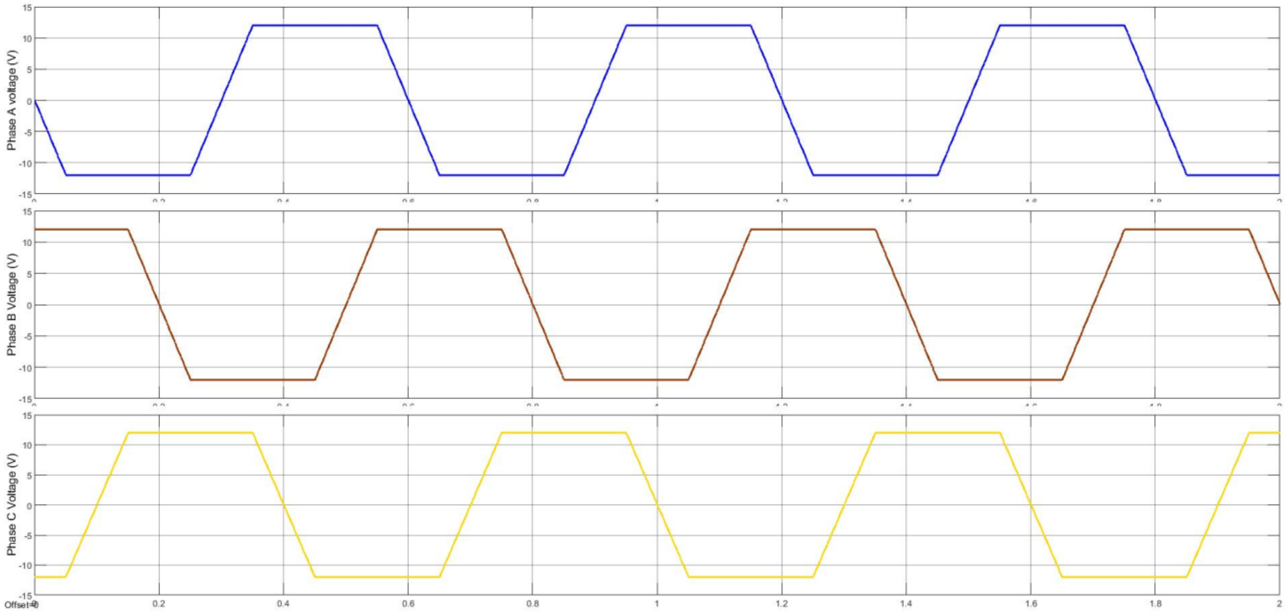

Figure 2 : Back EMF profile of the trapezoidal BLDC motor for 100rpm speed

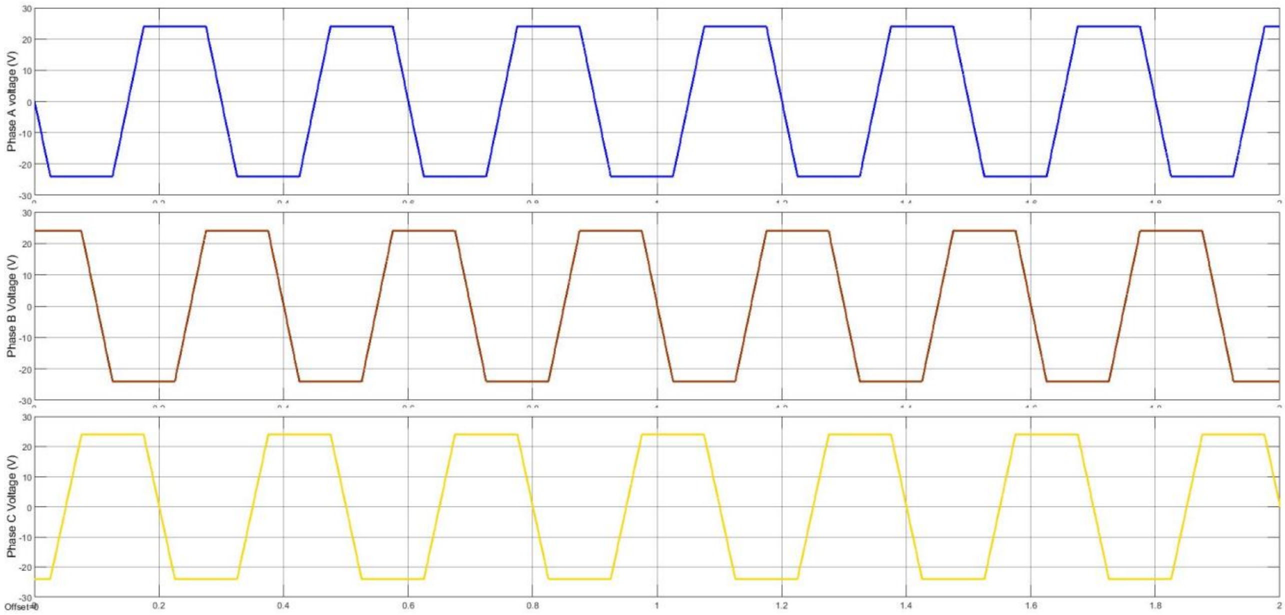

Figure 3 : Back EMF profile of the trapezoidal BLDC motor for 200rpm speed

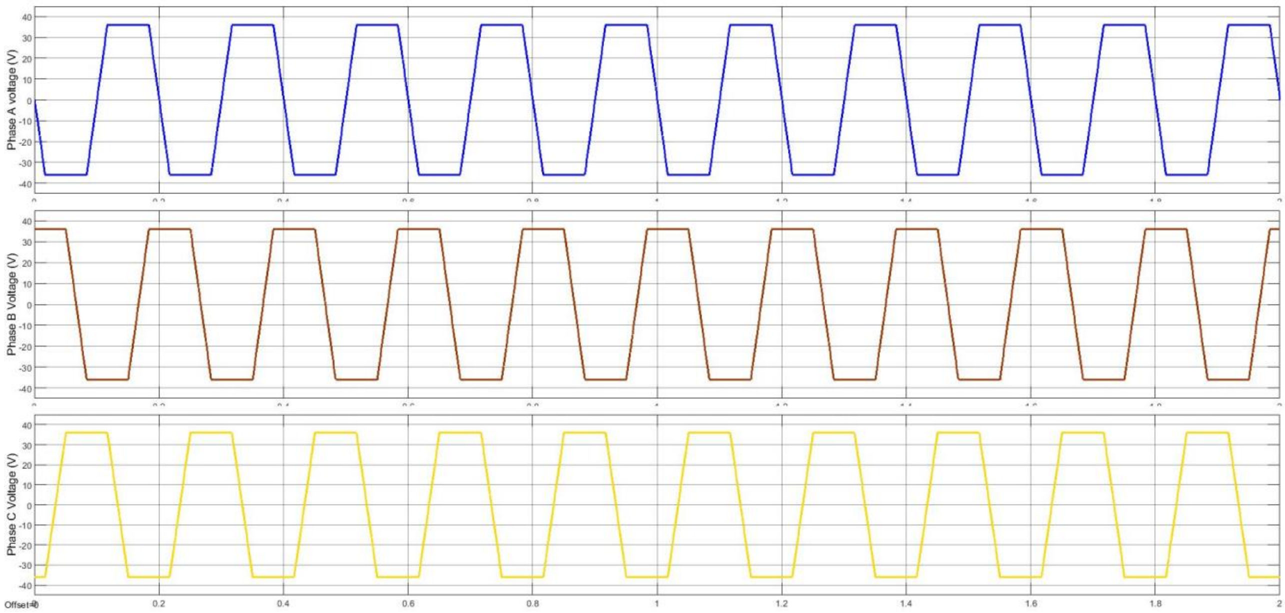

Figure 4 : Back EMF profile of the trapezoidal BLDC motor for 300rpm speed

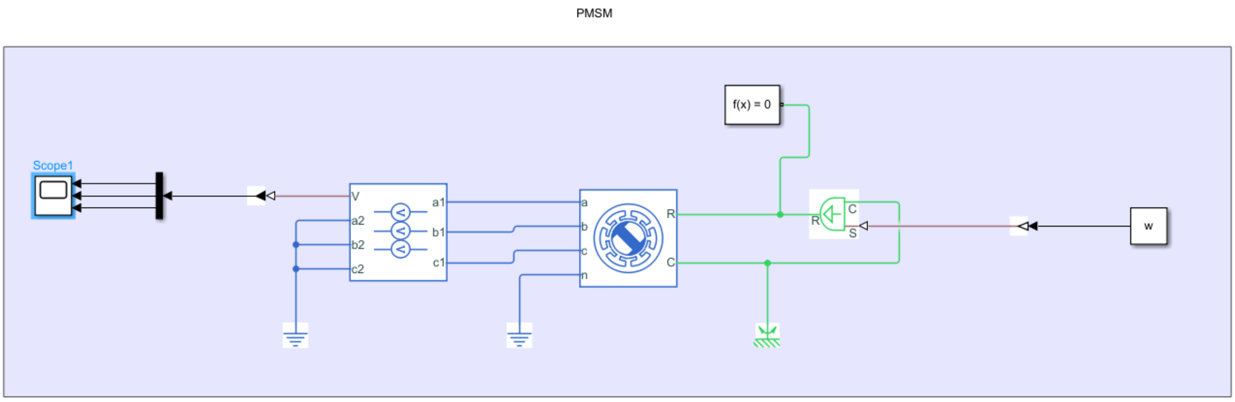

Figure 5 : SIMULINK model for back EMF profile of permanent magnet synchronous motor

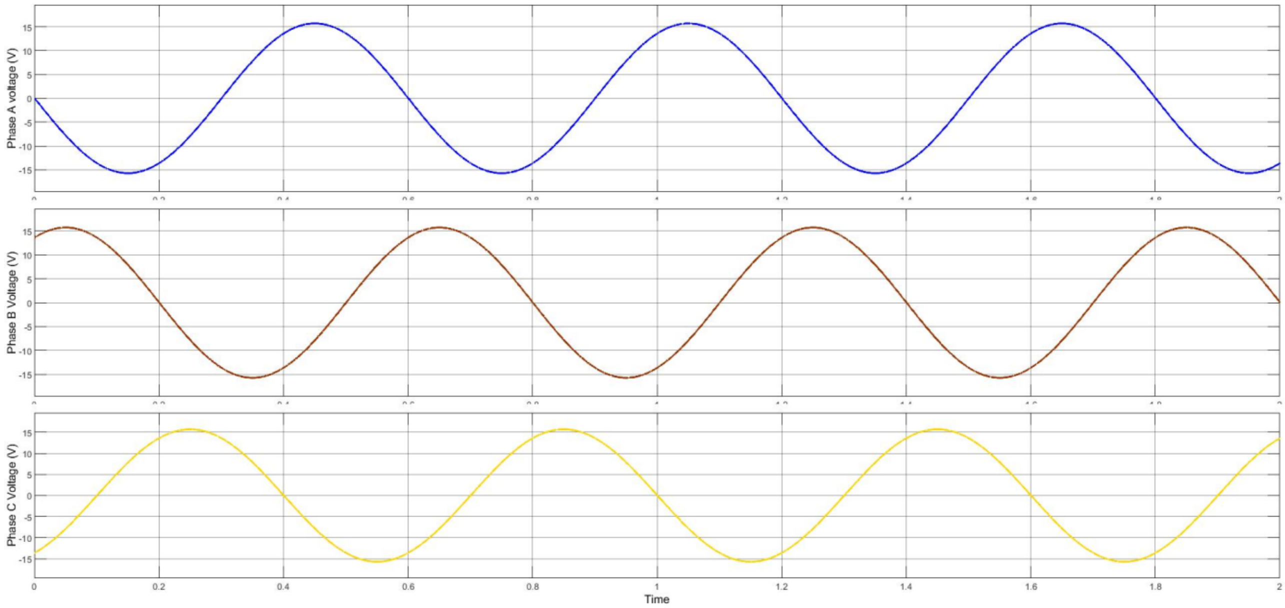

Figure 6 : Back EMF profile of the permanent magnet synchronous motor for 100rpm speed

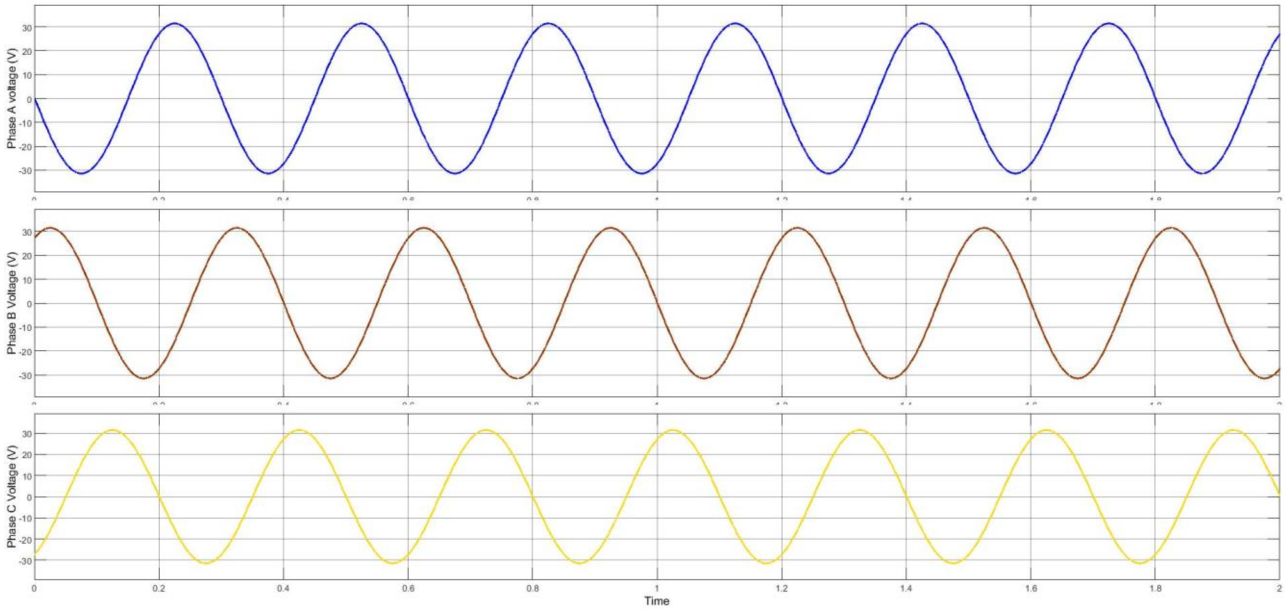

Figure 7 : Back EMF profile of the permanent magnet synchronous motor for 200rpm speed

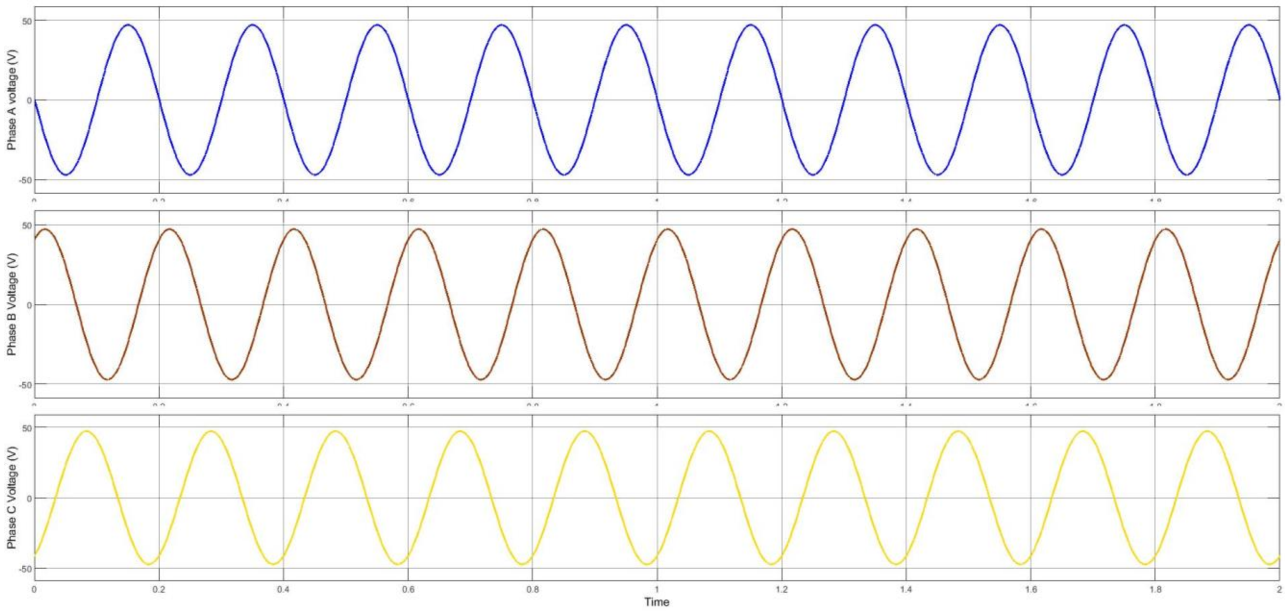

Figure 8 : Back EMF profile of the permanent magnet synchronous motor for 300rpm speed

PART B : SIX-STEP COMMUTATION OF A TRAPEZOIDAL BLDC MOTOR

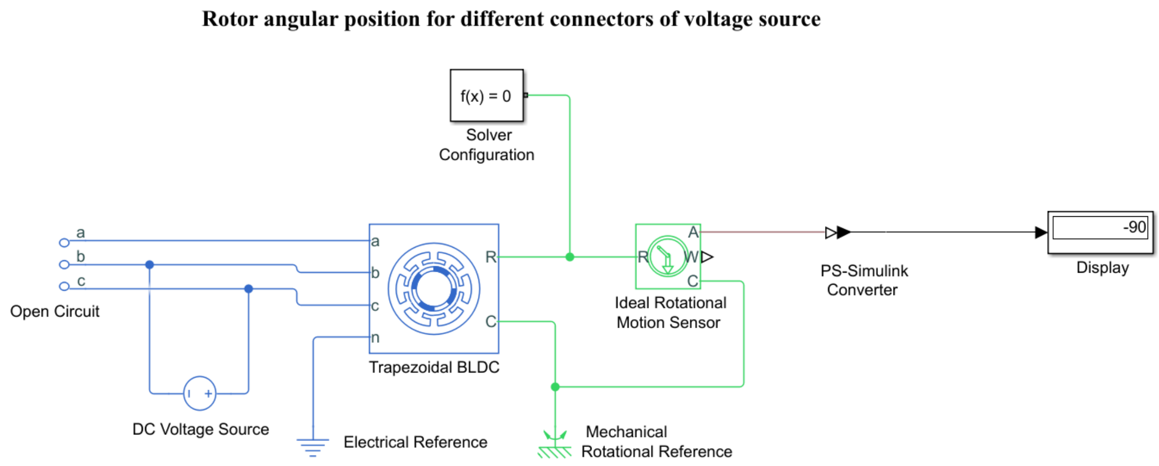

Figure 9 : SIMULINK model for observing trapezoidal BLDC rotor angular position for different connections of dc voltage source

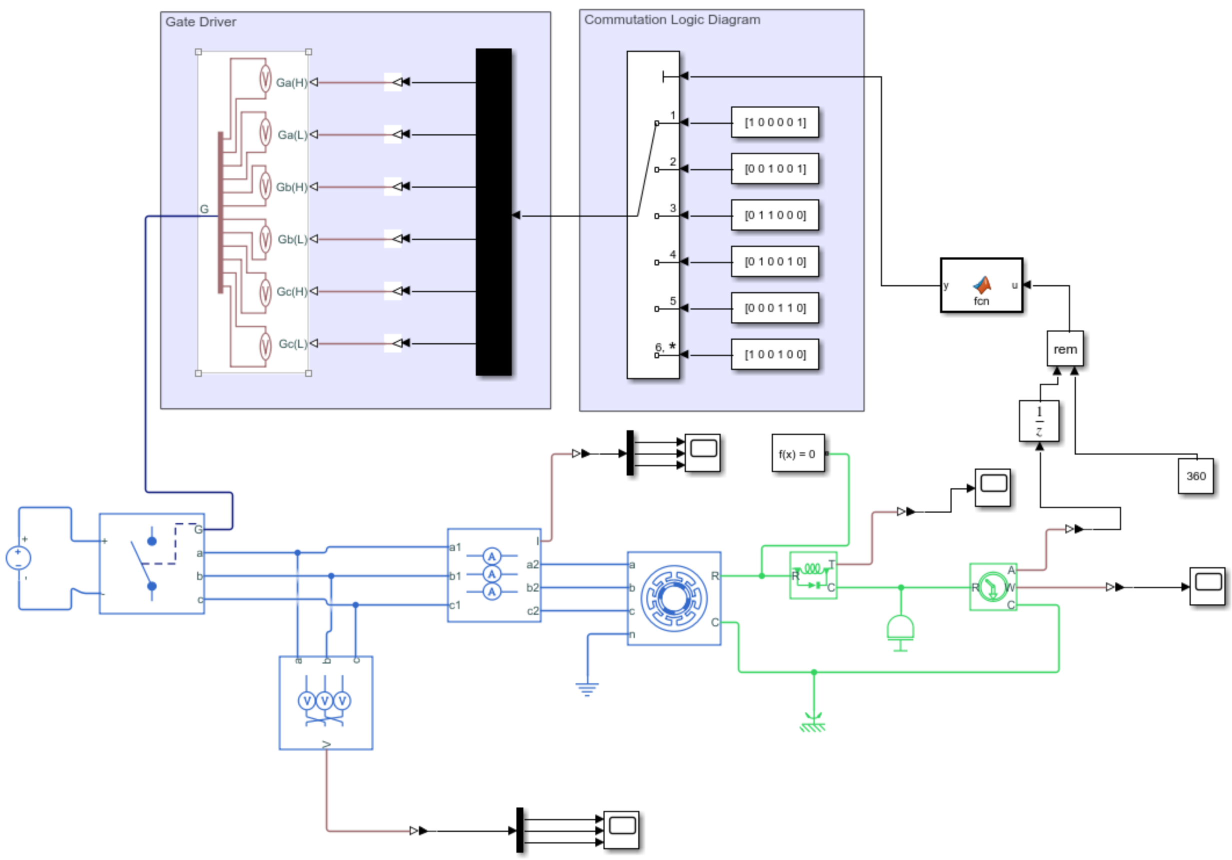

Figure 10 : SIMULINK model for observing the operation of a BLDC motor in positive direction

Editor - Block: EE6303_L3_3682_PartB_2/MATLAB Function

MATLAB Function

```matlab
function y = fcn(u)

if u<0
    u = u + 360;
end

if u>0 && (u<=30 || u>330)
        sequence = 1;
elseif u > 30 && u <= 90
        sequence = 2;
elseif u > 90 && u <= 150
        sequence = 3;
elseif u > 150 && u <= 210
        sequence = 4;
elseif u > 210 && u <= 270
        sequence =5;
else
        sequence = 6;
end

y = sequence;
```

Figure 11 : Position sensing logic of the BLDC motor driver for positive direction

1) BLDC characteristics for 50V supply voltage

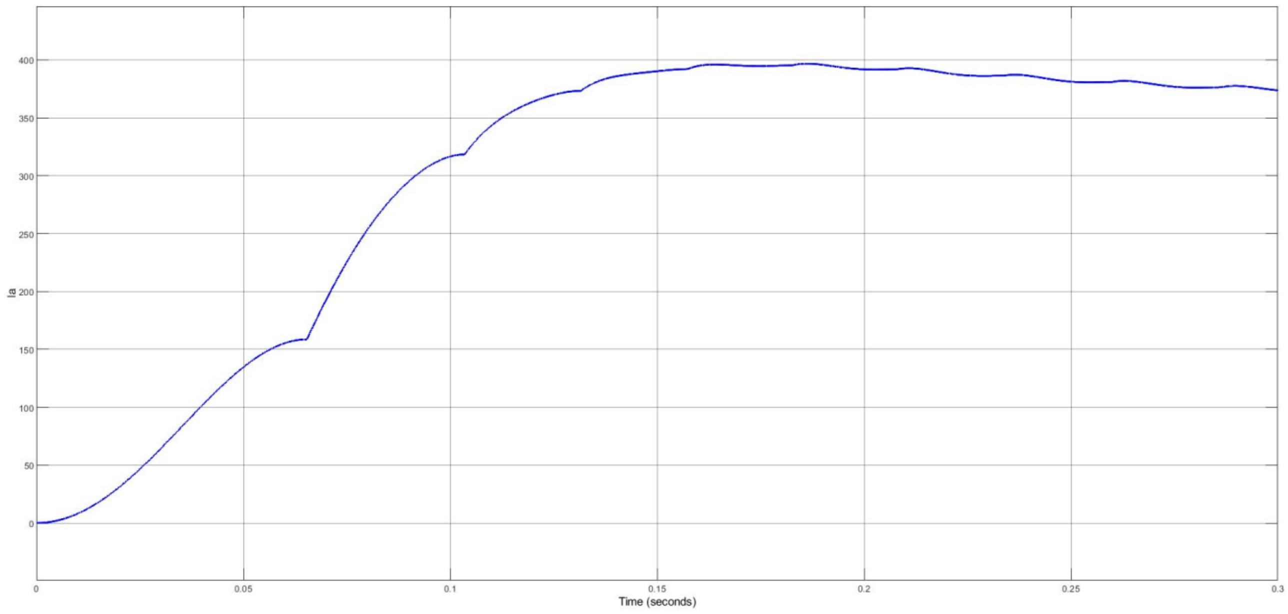

Figure 12 : Speed of the BLDC motor for 50V supply voltage

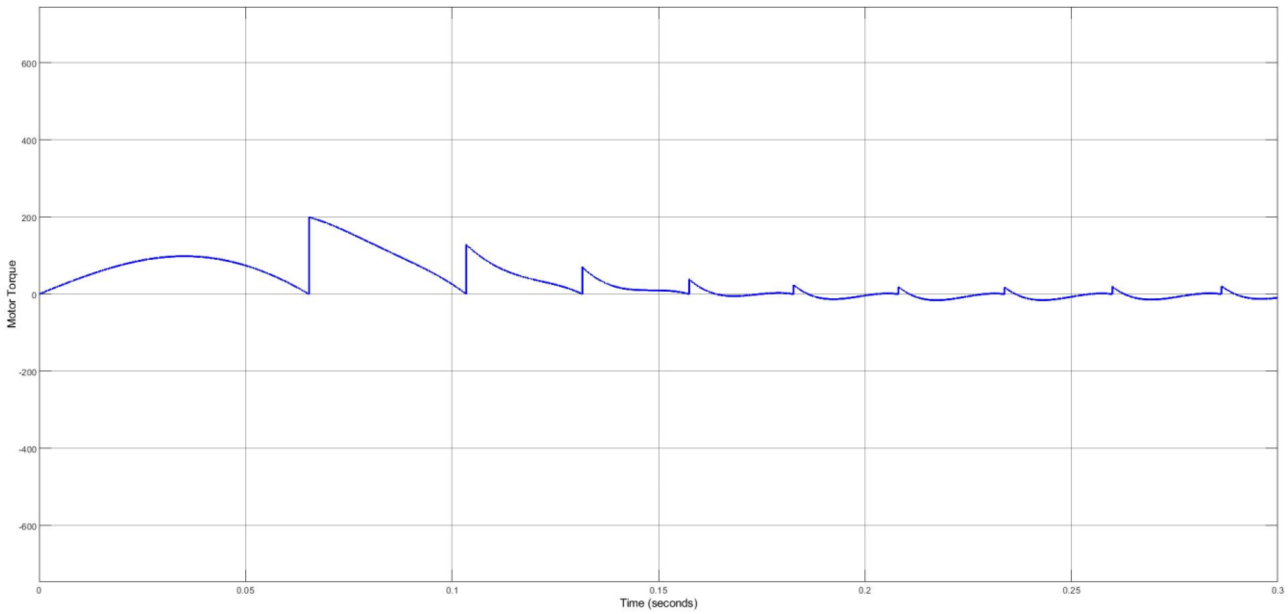

Figure 13 : Torque of the BLDC motor for 50V supply voltage

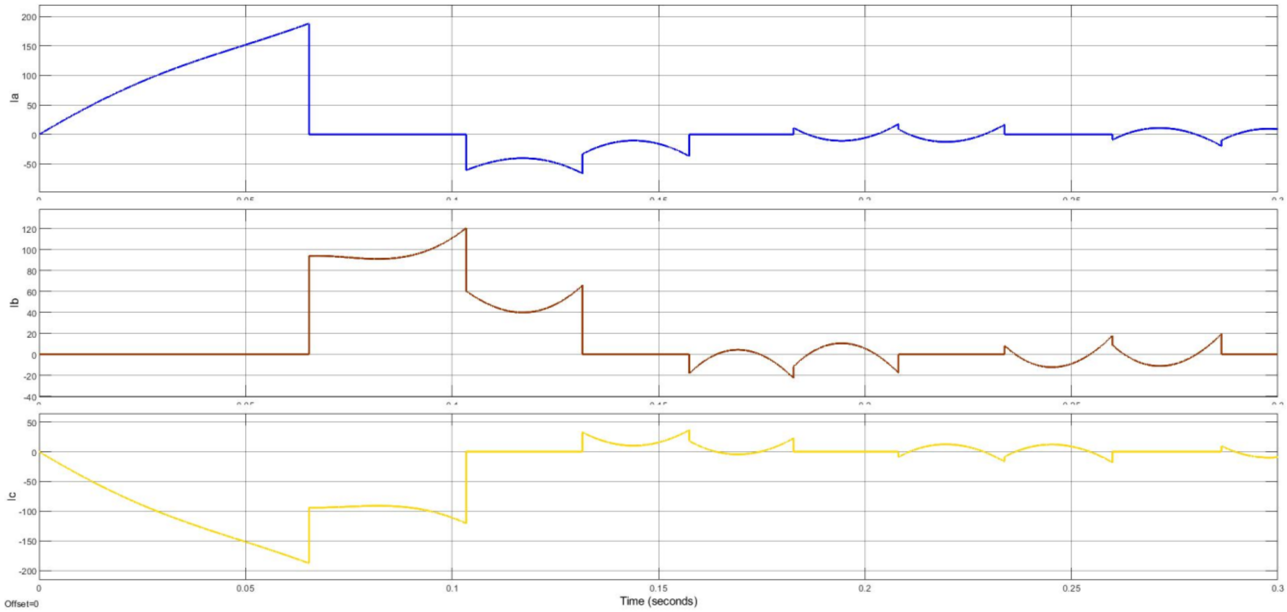

Figure 14 : Motor input line currents of the BLDC motor for 50V supply voltage

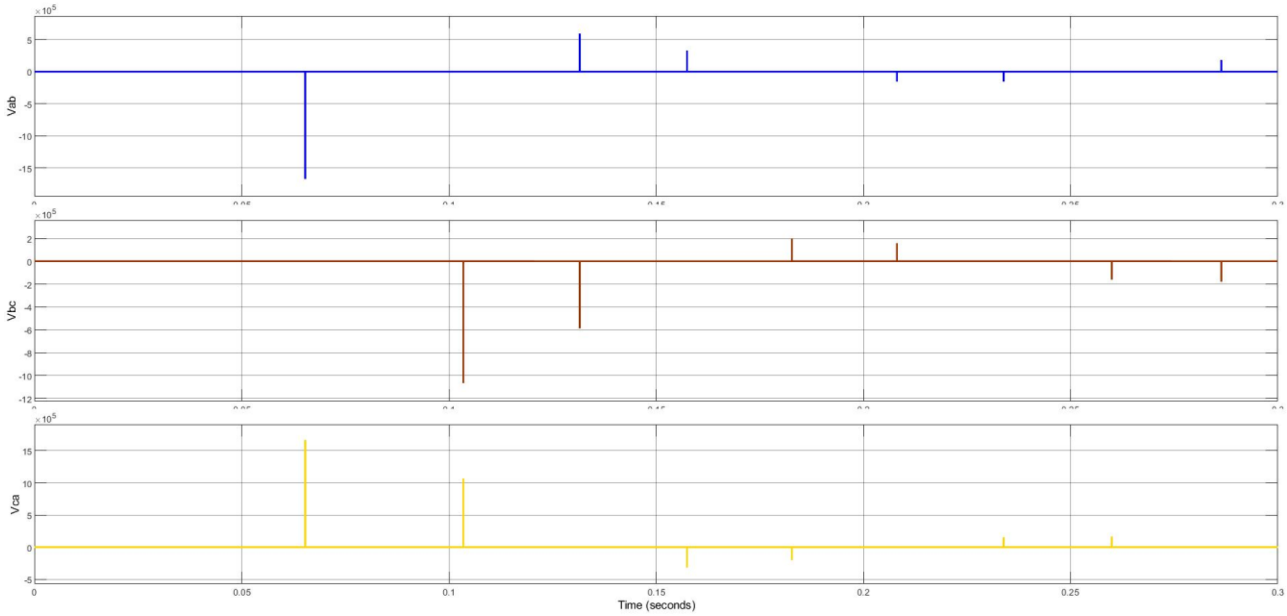

Figure 15 : Motor input line to line voltages of the BLDC motor for 50V supply voltage

2) BLDC characteristics for 100V supply voltage

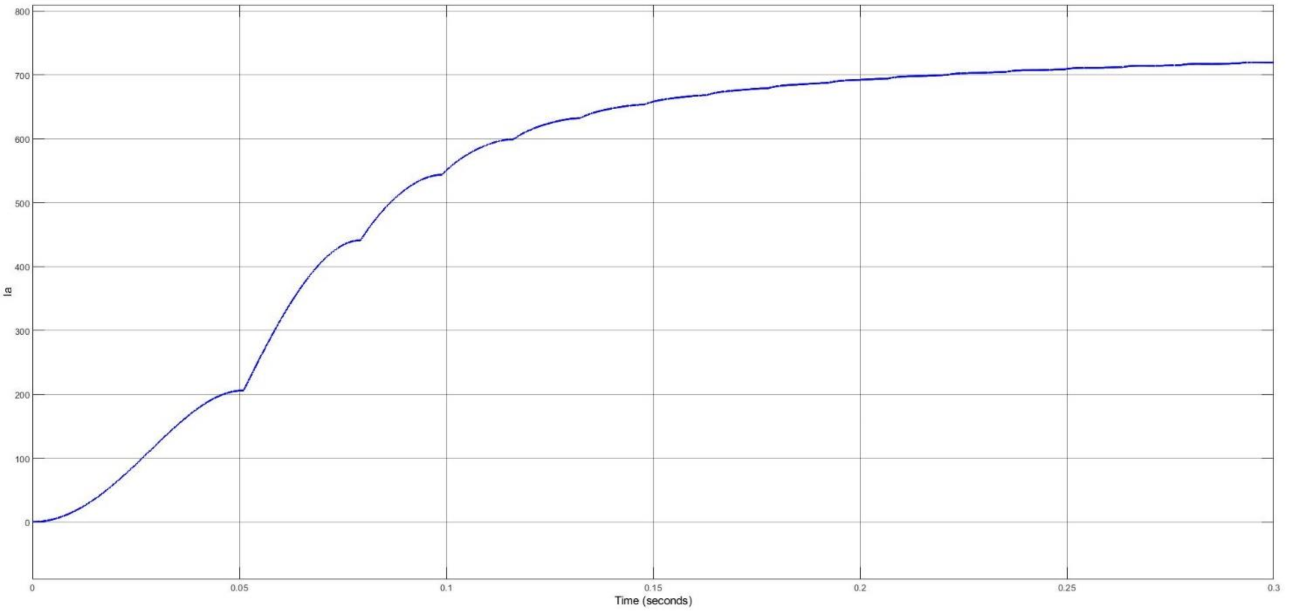

Figure 16 : Speed of the BLDC motor for 100V supply voltage

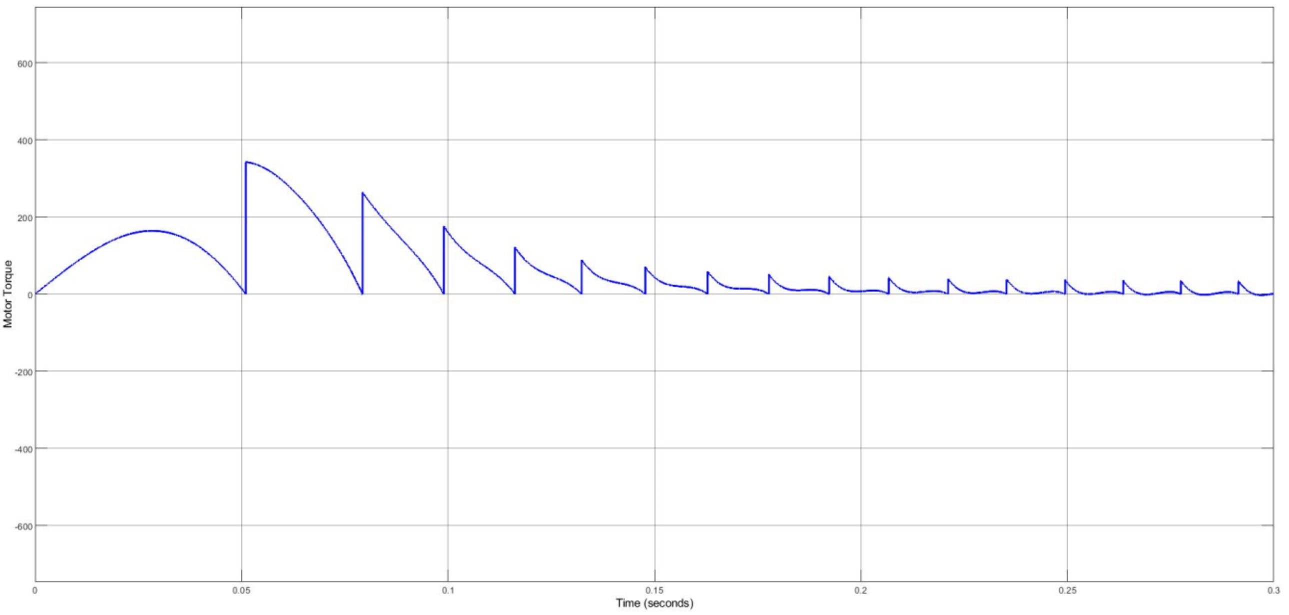

Figure 17 : Torque of the BLDC motor for 100V supply voltage

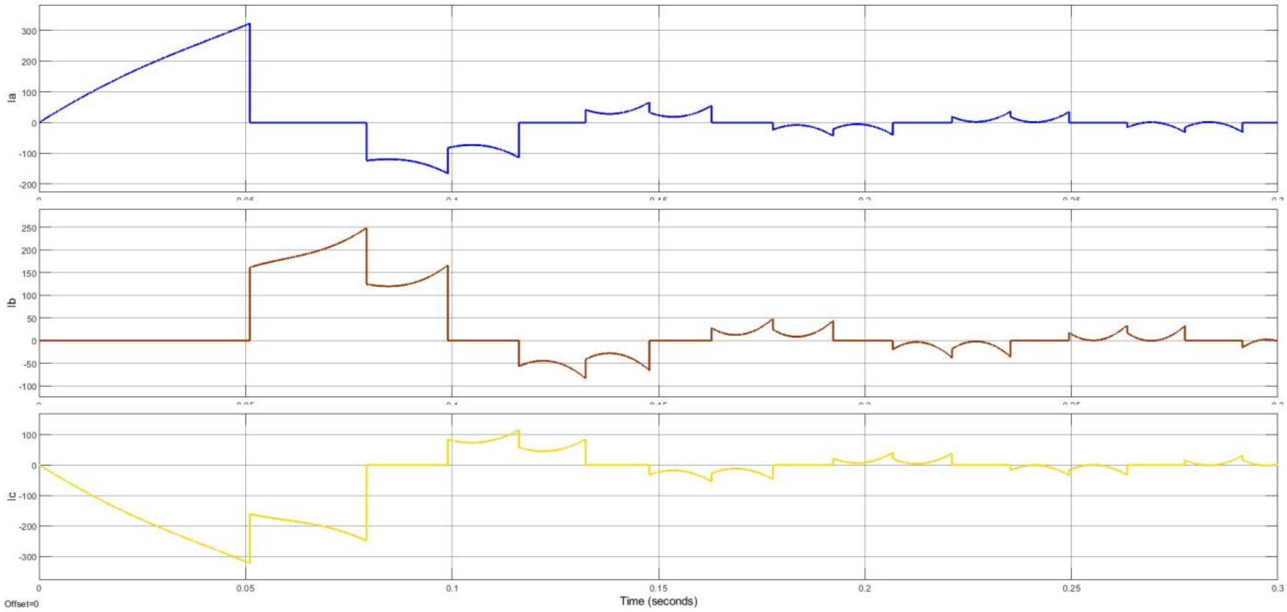

Figure 18 : Motor input line currents of the BLDC motor for 100V supply voltage

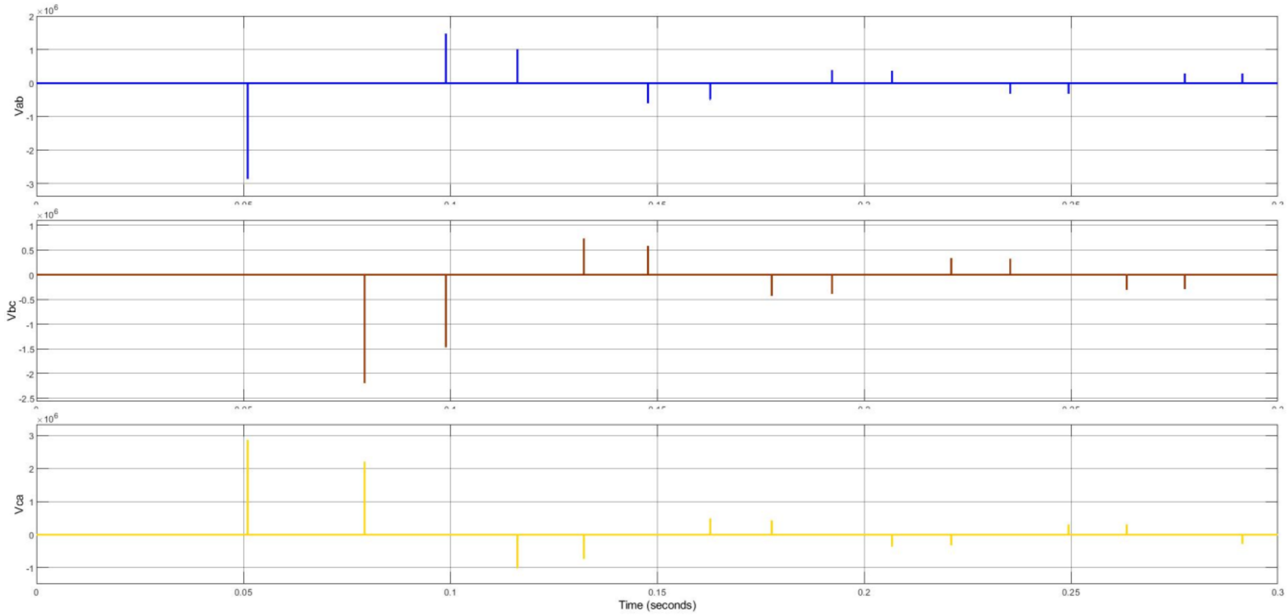

Figure 19 : Motor input line to line voltages of the BLDC motor for 100V supply voltage

3) BLDC characteristics for 150V supply voltage

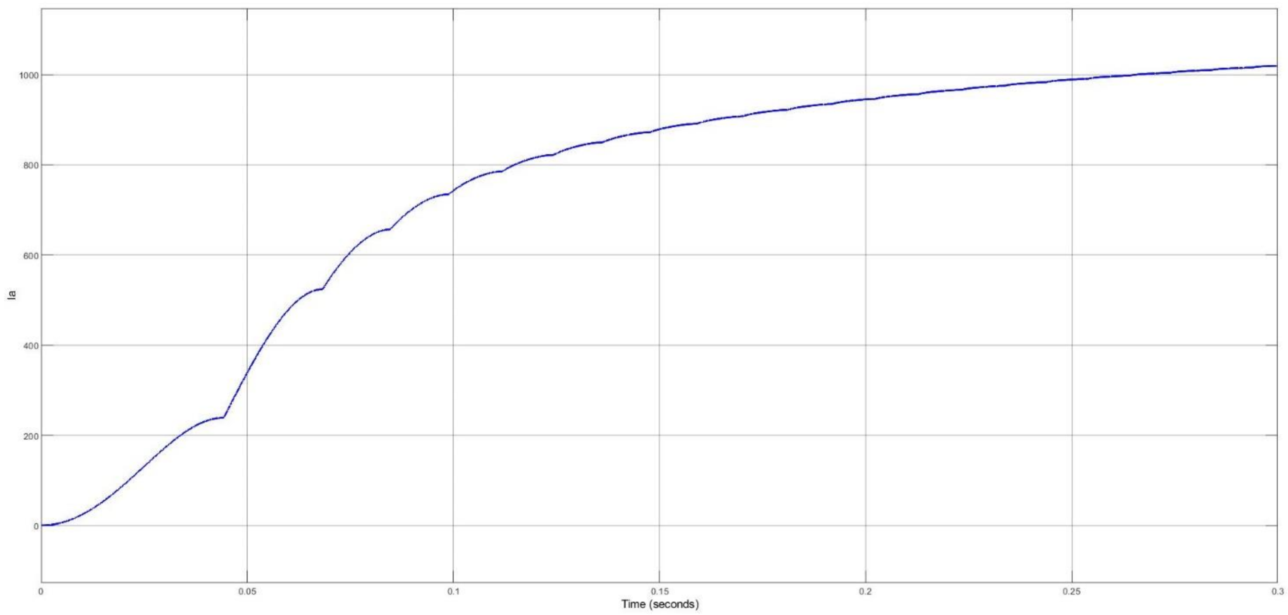

Figure 20 : Speed of the BLDC motor for 150V supply voltage

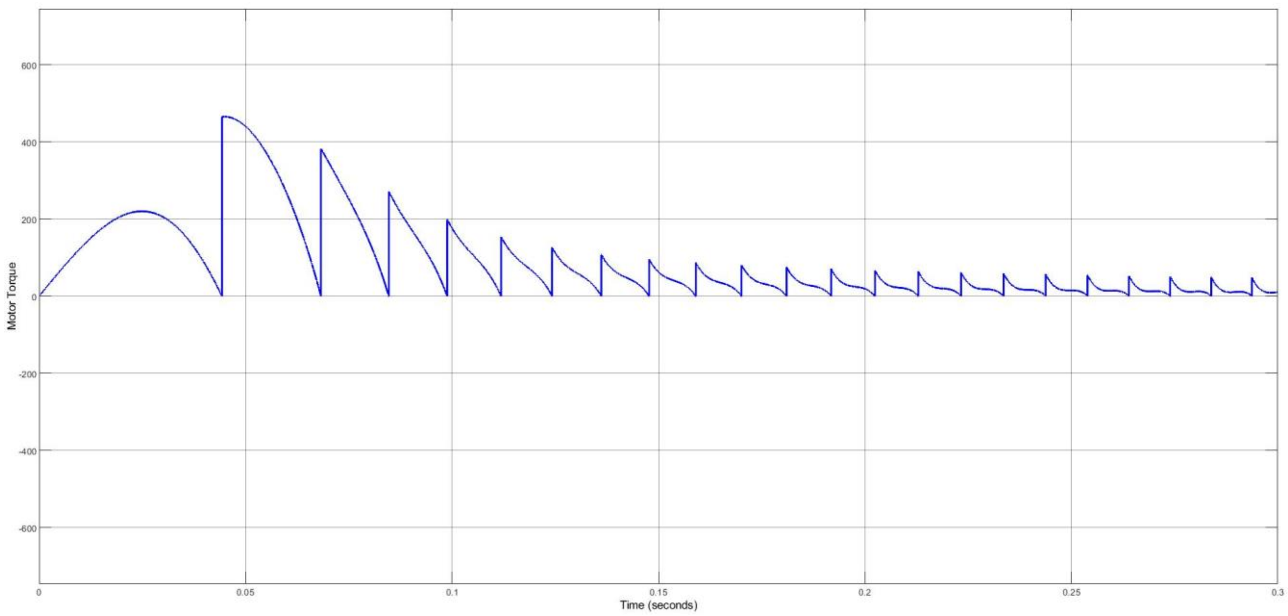

Figure 21 : Torque of the BLDC motor for 150V supply voltage

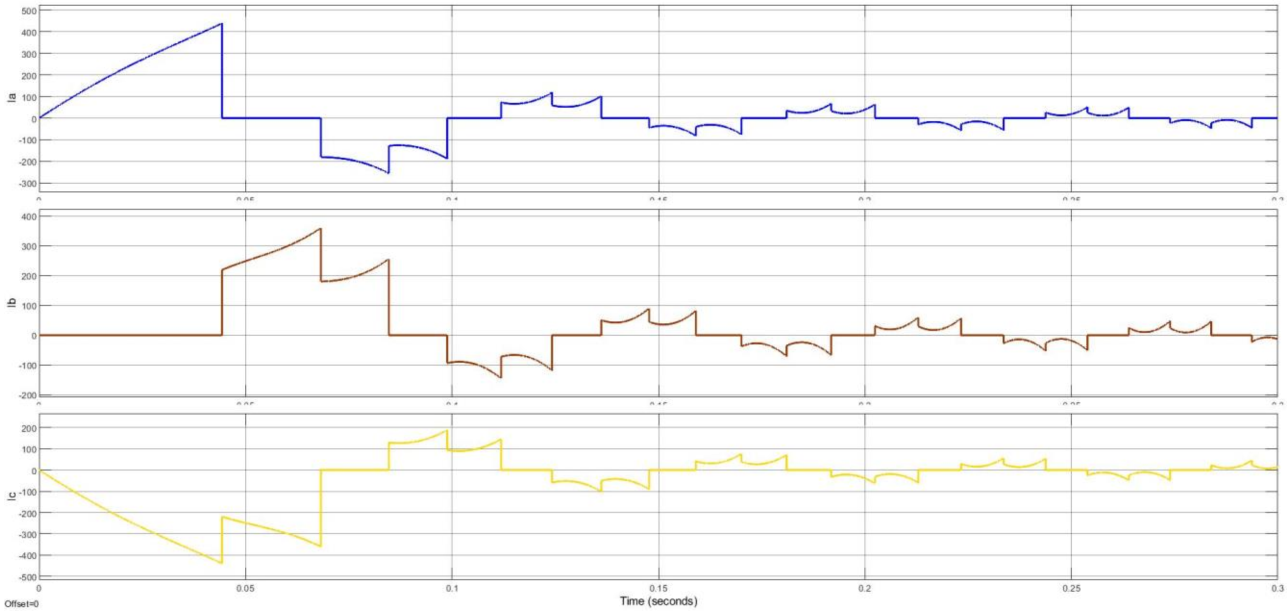

Figure 22 : Motor input line currents of the BLDC motor for 150V supply voltage

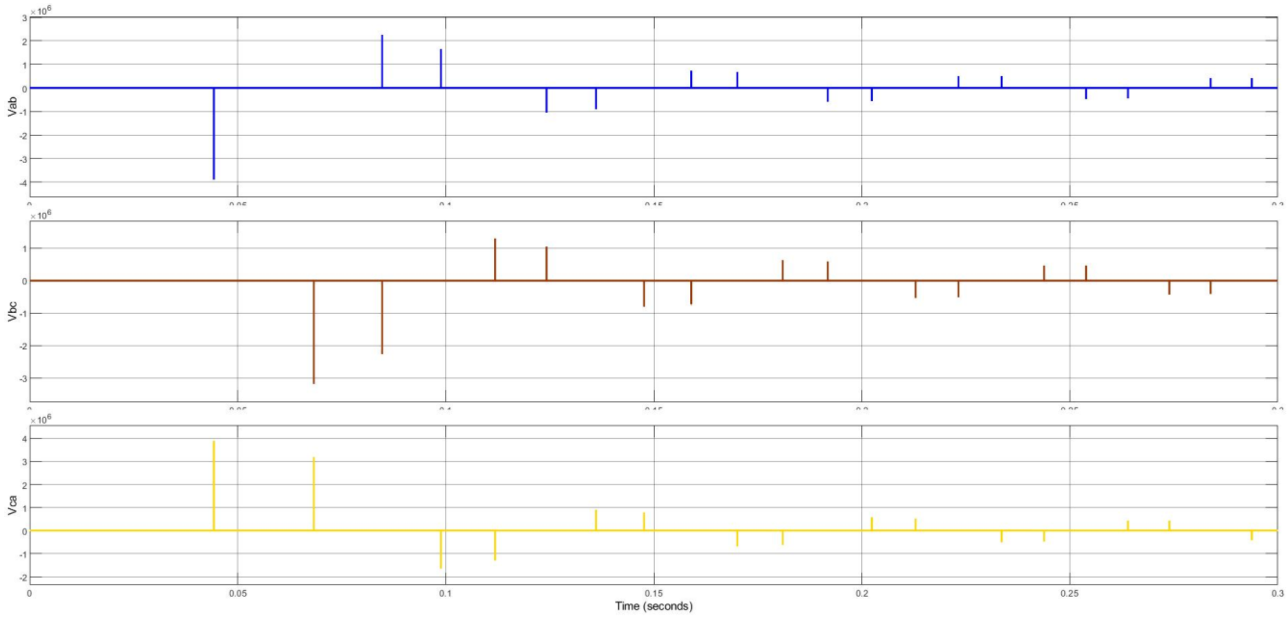

Figure 23 : Motor input line to line voltages of the BLDC motor for 150V supply voltage

2 TABULATION

PART B : SIX-STEP COMMUTATION OF A TRAPEZOIDAL BLDC MOTOR

Table 2 : Rotor angular position for different connections of DC voltage source

Positive Connection	Negative Connection	Rotor Angle (deg)
Phase a	Phase b	-30
Phase a	Phase c	30
Phase b	Phase c	90
Phase b	Phase a	150
Phase c	Phase a	-150
Phase c	Phase b	-90

Table 3 : Commutation logic to drive the BLDC motor in positive direction

AH	AL	BH	BL	CH	CL	Positive Connection	Negative Connection	Rotor Angle (deg)
1	0	0	0	0	1	Phase a	Phase c	30
0	0	1	0	0	1	Phase b	Phase c	90
0	1	1	0	0	0	Phase b	Phase a	150
0	1	0	0	1	0	Phase c	Phase a	-150
0	0	0	1	1	0	Phase c	Phase b	-90
1	0	0	1	0	0	Phase a	Phase b	-30

Table 4 : Commutation logic to drive the BLDC motor in negative direction

AH	AL	BH	BL	CH	CL	Positive Connection	Negative Connection	Rotor Angle (deg)
1	0	0	1	0	0	Phase a	Phase b	-30
0	0	0	1	1	0	Phase c	Phase b	-90
0	1	0	0	1	0	Phase c	Phase a	-150
0	1	1	0	0	0	Phase b	Phase a	150
0	0	1	0	0	1	Phase b	Phase c	90
1	0	0	0	0	1	Phase a	Phase c	30

3 DISCUSSION

1)

PART A : BACK EMF PROFILES OF TRAPEZOIDAL AND SINUSOIDAL BLDC MOTORS

The block diagram and waveforms of a trapezoidal BLDC motor for three different angular frequencies are shown in Figures 1 through 4. Similarly, for the sinusoidal BLDC motor, these are shown from Figures 5 through 8. It is observed that with the increase in the rotational speed, the magnitude and frequency of the induced back EMF also rise according to the relation for synchronous speed:

$$N_s = \frac{120f}{p}$$

When ns is 100rpm, frequency is 1.667Hz and period is 0.6s.

When ns is 200rpm, frequency is 3.333Hz and period is 0.3s.

When ns is 300rpm, frequency is 5.000Hz and period is 0.2s.

Eventually, PMSM and BLDC motors are synchronous motors, as both follow the synchronous speed relationship of synchronous machines.

PART B : SIX-STEP COMMUTATION OF A TRAPEZOIDAL BLDC MOTOR

The rotational speed of the BLDC motor for various supply voltages of 50V, 100V and 150V are shown in figure 12, 16 and 20. While increasing from zero, the rotational speed has some small ripples due to the six-step commutation of the controller. The rotational speed reaches to a steady speed with the supply voltage. The torque of the BLDC motor for different supply voltages of 50V, 100V, and 150V are shown in figures 13, 17, and 21. It has a large number of ripples and torque is not constant. It also is caused by six-step commutation of the controller. In the start of the motor, the highest torque can be observed. It decreases as the speed of the motor increases and then reached a constant value. The reason is that load starting to rotate hence the torque needs from the motor are decreasing with time. The input line current of BLDC at different supplied voltages of 50V, 100V, and 150V are shown in figure 14, 18, and 22 respectively. The current is varying in steps-like manner as the commutation is done by the controller. While the load is starting to turn, the amplitude of the current is decaying with time, thus reducing the torque applied by the motor. The time period of such changes in current is also going down as the motor gains speed and approaches the steady value. The input line to line voltages of the BLDC motor for different supply voltages of 50V, 100V and 150V are shown in figure 15, 19 and 23. There are high voltage spikes present due to the back EMF produced by the motor during the commutation. As the model does not have back EMF protection diodes, these large voltage spikes may damage it if the controller is built using actual components. This means that the time duration of spikes is also becoming shorter with time and reaching a steady value, thus showing the commutation interval is getting shorter in time to reach a steady value.

2) There is a relation between the supply voltage and the motor's speed: the more the supply voltage, the more the speed of the motor increases. This can be seen in Figures 12, 16, and 20. In this simulation, the supply voltage controls the speed of the motor. A controlled voltage source with a PID controller operating with negative feedback can maintain the motor at a constant speed of 1500 rpm. The controller modified with these implementations is shown in Figure 24, and the characteristics of its speed control are shown in Figure 25. This is again not a practical solution that could be employed in real applications since it would require another voltage controller capable of supplying large currents in order to control supply voltage. Actual BLDC motor drives control the motor speed using methods like pulse-width modulation. In PWM, during every commutation, instead of supplying continuous power, it connects the supply only for a portion of time, which is proportional to the required speed output of the motor.

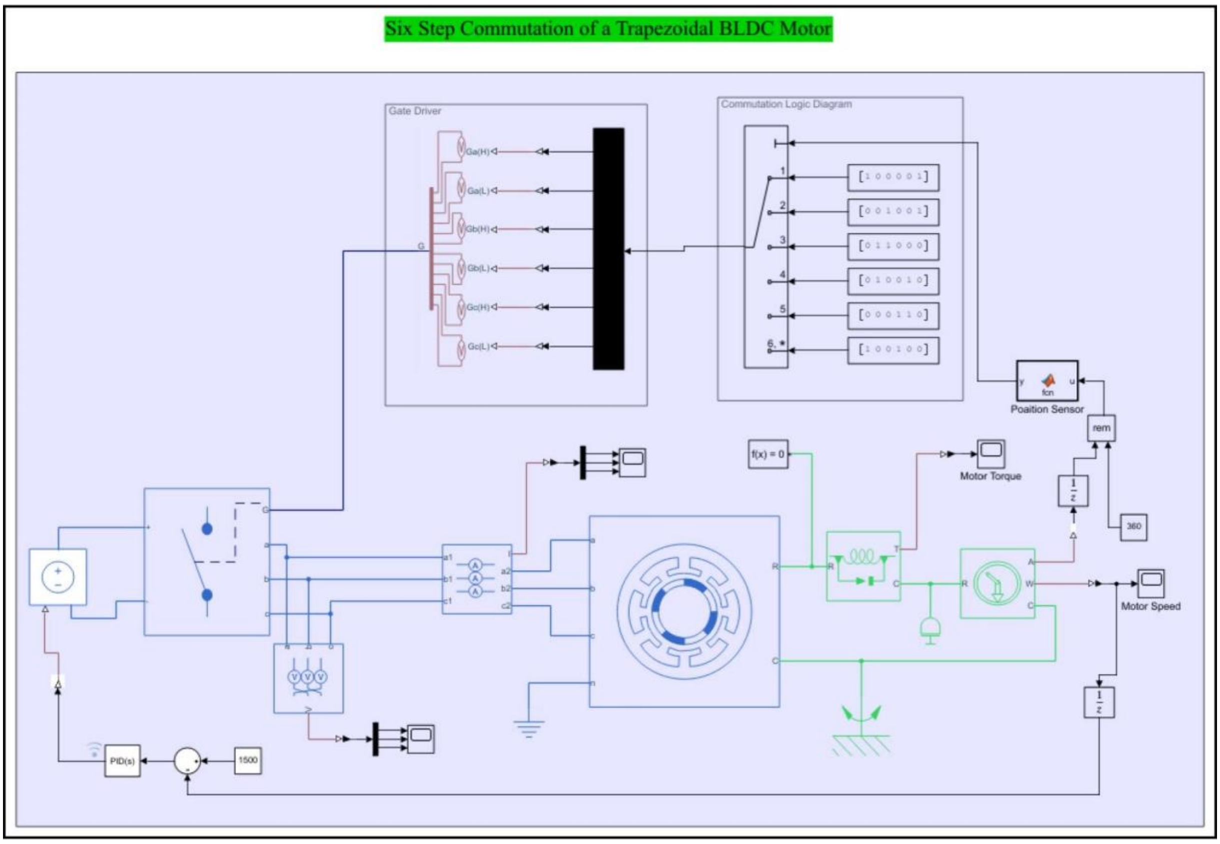

Figure 24:BLDC controller model with PID based speed control

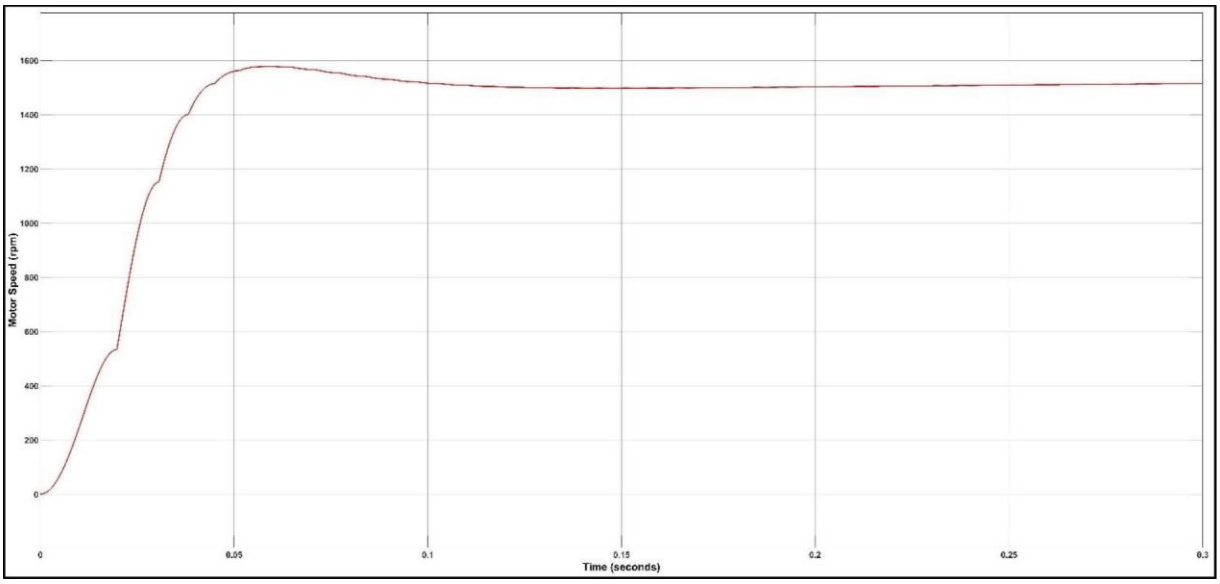

Figure 25:Reponse of the BLDC motor controller with PID speed controller