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dSpace Based Implementation of Closed Loop Brushless DC Motor Control

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Abstract—*Brushless Direct Current Motors or BLDC Motors are currently growing in popularity owing to the advent of power electronic switching circuits and further improvements in sensing technologies. As such, now, a lot of fields employ this machine for varied purposes primary among them being motion control, positioning and actuation systems. The industrial engineering industry is shifting to BLDC use due to its high power density, good speed – torque characteristics, high efficiency and wide-speed ranges. Also being brushless, they require lesser maintenance than their brushed counterparts. The paper discusses the Modeling and Simulation of Closed Loop BLDC Motor Control along with implementation of its open loop control for running the motor first using ASIC UC3625 and then using dSpace control unit. Basically, control of BLDC motor consists of supplying the gating pulses for the inverter bridge configuration in order to excite the phases in a particular sequence. Hall sensor input is fed back to the control circuit which then determines which phase to excite next in order to move the motor in a particular direction. This control can then be applied in a closed loop scheme, where a reference input can be used to adjust the output of the control circuit to get the desired gating pulses. This reference input is usually taken as the speed for fixed speed operation or to provide variable speed operation to the user independent of the load. For this, the speed is also taken as an output from the motor normally by using a shaft encoder. It is then fed to the control circuitry after suitable conversion. Speed control results and closed loop performance of the scheme will be reported on the above developed system.*

1. INTRODUCTION

The BLDC Motor is similar in construction to a Permanent Magnet Synchronous Machine (PMSM). It consists of a permanent magnet rotor and three phase distributed windings on the stator. A position sensor is used to sense position of rotor. The position sensor can be an optical encoder or a Hall Effect sensor. Electronic commutation is performed by a logic circuitry that is needed external to the machine. This logic circuitry serves to control the speed of the motor by controlling the switching of the inverter gates. [1, 2]

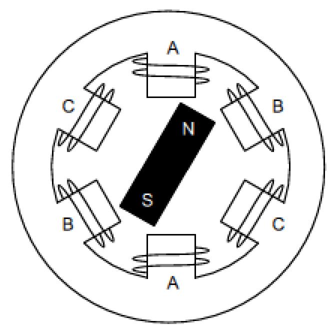

Fig. 1: Simplified Structure for a single rotor pole machine

Principle of Operation

The BLDC Motor as stated earlier needs a certain logic circuitry for controlling the commutation sequence. The principle of the BLDC motor is, at all times, to energize the phase pair, which can produce the highest torque. To optimize this effect the back EMF shape is trapezoidal. The combination of a DC current with a trapezoidal back EMF makes it theoretically possible to produce a constant torque. In practice, the current cannot be established instantaneously in the phase of a motor; as a consequence the torque ripple is present at each 60° phase commutation. The BLDC motor is characterized by a two phase ON operation to control the inverter. In this control scheme, torque production follows the principle that current should flow in only two of the three phases at a time and that there should be no torque production in the region of the back EMF zero crossings.[3]

Hall Effect sensors have been used in the machine under study. The Hall Effect sensor positions and the corresponding switching sequence are given in Table 1. The sequence can be determined by drawing excitation diagrams for each of the rotor positions (displaced by 60 degrees) and the corresponding stator winding excitation.

Table 1: Hall sensor pattern and Excitation Sequence [4]

H1	H2	H3	Q1	Q2	Q3	Q4	Q5	Q6
0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	1	1	0
0	1	0	0	1	1	0	0	0
0	1	1	0	1	0	0	1	0
1	0	0	1	0	0	0	0	1
1	0	1	1	0	0	1	0	0
1	1	0	0	0	1	0	0	1
1	1	1	0	0	0	0	0	0

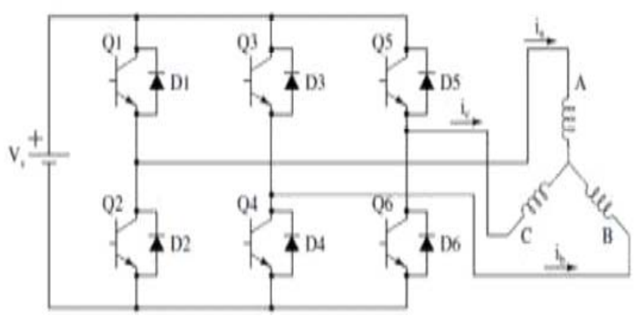

Fig. 2: Inverter Connections to Phases [4]

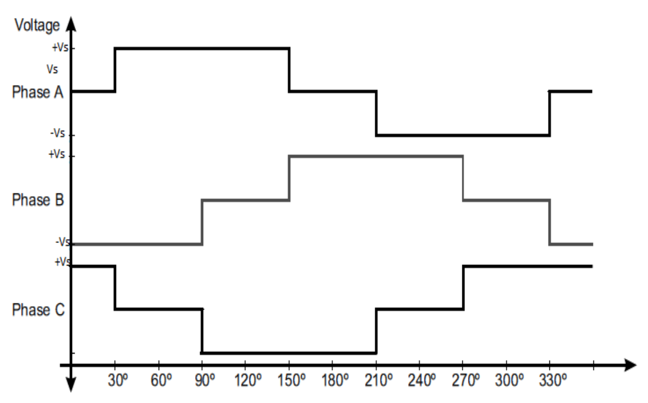

Fig. 3: Voltage Profile applied to the phases [5]

2. MACHINE SPECIFICATIONS

Table 2: Machine Specifications

Rated Voltage	48 V
Rated Wattage	800W
Maximum Speed	500 rpm
Rated Torque	17.8 N-m
Number of rotor poles	4

3. SIMULINK MODEL

The SIMULINK model used the following basic structure as derived from the block diagram

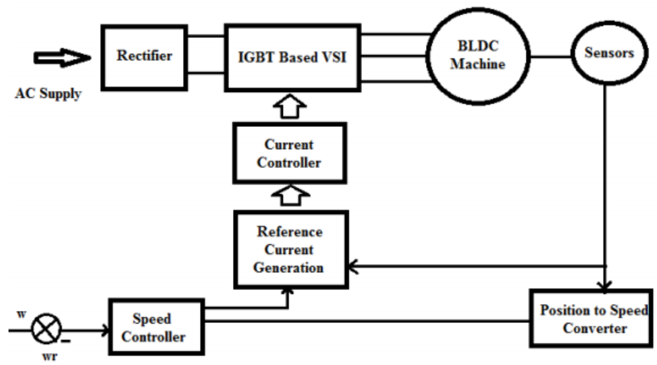

Fig. 4: Simplified model [6-8]

The SIMULINK model is shown as below:

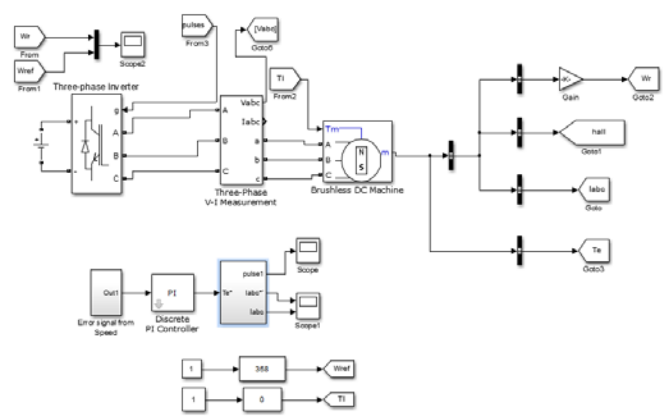

Fig. 5: SIMULINK model

From among the measurable variables from the machine, the speed is compared to a reference speed. The error signal thus obtained, is sent through a discrete PI controller as shown. The output of the PI controller is used to calculate the reference currents which are compared to the actual currents fed back from the machine in the following subsystem:

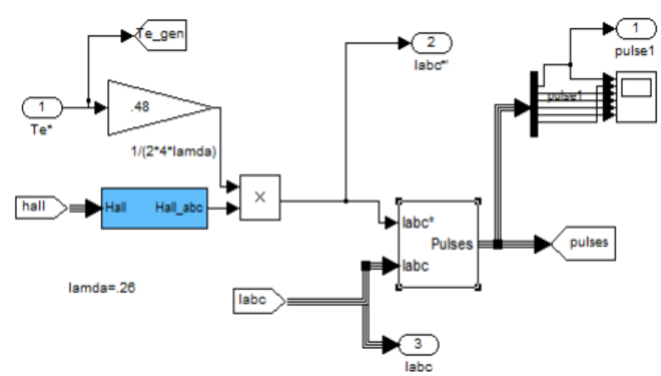

Fig. 6: Generation of Pulses to Drive IGBT Gates

Pulses for switching are obtained from the above given logic diagram which are fed to the gates of the power BJTs/ MOSFETs or IGBTs that make up the inverter.

Results of Tuned Closed Loop Model

In the given model, the machine was subject to the following speeds at the given loads for variable time as follows:

Table 3: Experimental values for Tuned Model

Time (s)	Speed (RPM)	Load (N-m)
0	358	5
0.5	358	2
1	358	3
1.5	200	0
2	200	4
2.5	200	1
3	-358	1.5
3.5	-358	2
4	-358	-2
4.5	100	3
5	100	1
5.5	100	5
6	0	0
6.5	-150	2.5
7	-150	0

The following shows the output waveforms from the above SIMULINK model:

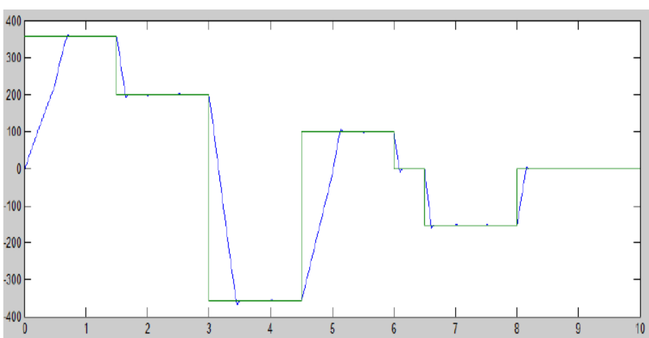

Fig. 7: Actual Speed and Reference Speed

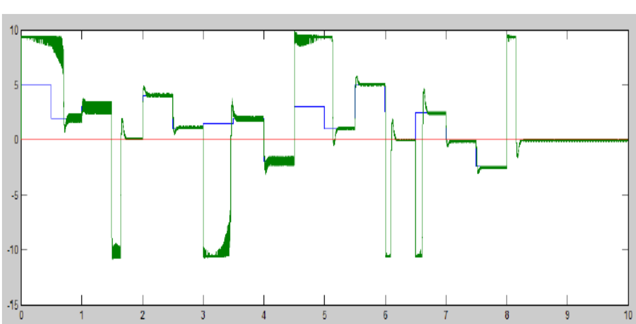

Fig. 8: Actual Torque and Set Torque

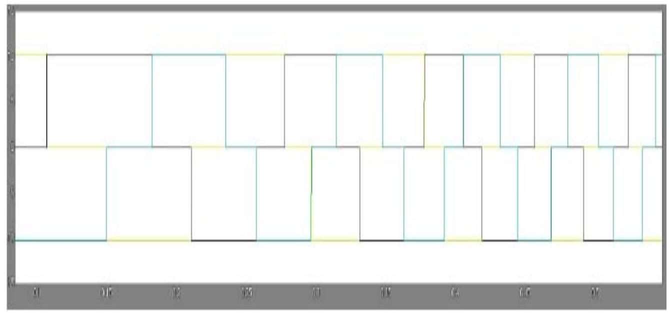

Fig. 9: Calculated Current Output

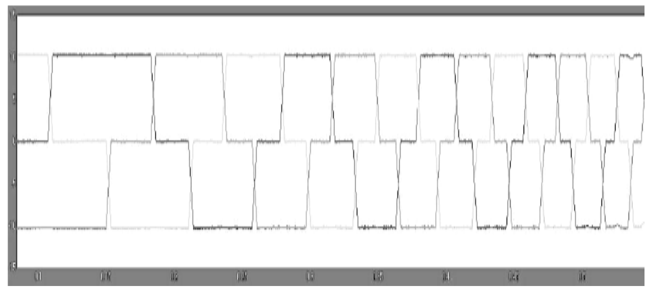

Fig. 10: Actual Current Output Waveform

The BLDC machine is started at t=0. It is seen that rise time of system is 0.75 unit time and an overshoot of 0.005% is seen in speed. At starting $\mathbf{w_{ref}}$ **= 358 rpm** and $\mathbf{w_{actual}}$ **= 0 rpm t**hus error seen by controller is very large and Torque developed by machine saturates to its highest value leading to rated current being drawn into machine. As **error =** $\mathbf{w_{ref} - w_{actual}}$ decreases, electromagnetic torque developed by motor starts decreasing and quasi-square type of current is fed into motor. When the **error = 0**, current drawn by motor decreases to a smaller value. As is seen from the above curves the machine is able to follow the set reference speed and is able to account for the vari**ations in torque values. Torques** greater than 6 N-m do not produce a good output and haven't been used in the same. The values for K_P and K_I are 2.62 and 100 respectively in the PI Controller for this system.

Hardware Implementation

In the first attempt, IC UC3625 was used, this is a BLDC controller IC from Texas Instruments. The following results were obtained:

Table 4: Actual Results from UC3625 Control Unit

S. No.	VDC(V)	IA (A)	IB (A)	IC (A)	Speed (rpm)	Duty Cycle
1	52.6	2.4	2.6	2.6	48	20
2	52.6	3.4	3.5	3.5	128	30
3	52.6	3.7	3.9	3.9	206	35
4	52.6	5.0	5.2	5.1	312	42.1
5	52.6	6.2	6.8	3.7	356	55

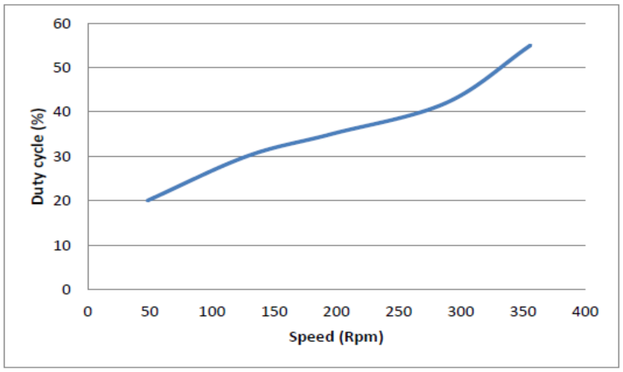

Fig. 10: Speed vs. Duty Cycle Curve

It is observed that the speed vs. duty cycle curve is almost linear as expected.

In the second attempt, the dSpace environment was used to simulate and run the SIMULINK model. Adequate connections were provided using the ADC and Digital I/O ports to connect the hardware to the dSpace module.

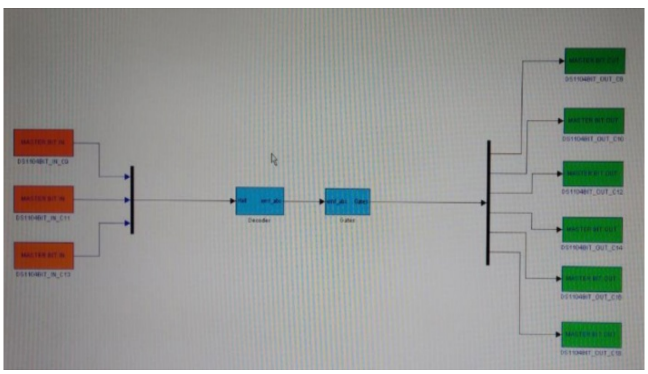

Fig. 11: I/O interface with Logic Sequence of dSpace

The pulse signals from the dSpace module are linked via a gate driver circuit to the inverter. The gate driver circuit is used to convert the 5V signal to a 15V signal driven from a separate power source to drive the gates of the IGBTs used in the inverter.

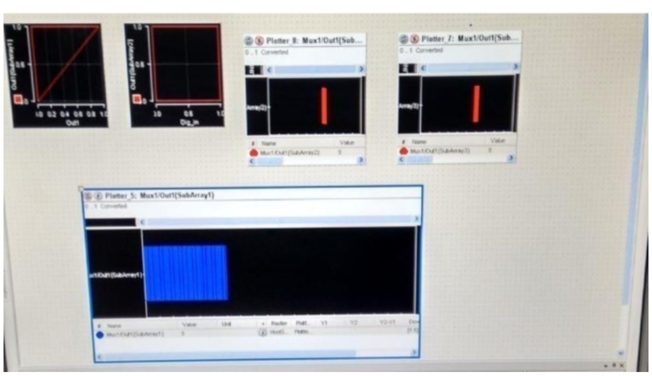

Fig. 12: Real Time Hall effect sensor Input waveforms

The machine was operated in open loop mode using the dSpace module and satisfactory results were obtained in speed control by varying the duty cycle of the PWM pulses to the gates. An approximately linear speed vs. duty cycle curve was obtained for the same.

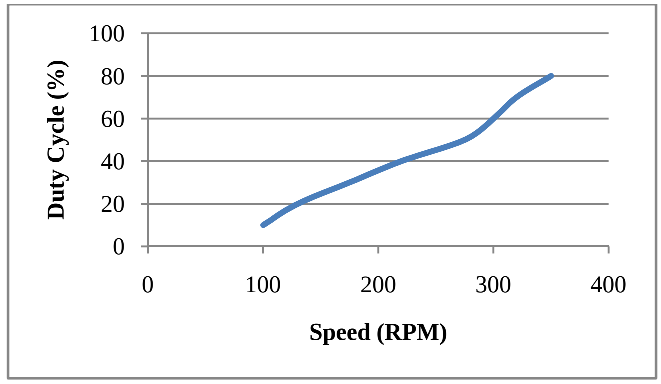

Fig. 13: Speed vs. Duty Cycle curve for dSpace based control

4. CONCLUSION

It is observed that a highly precise tuned closed loop control model of a BLDC control system can be developed using SIMULINK. The output waveforms of speed, torque and current correspond to the expected waveforms. The same model can be used directly in the dSpace module for closed loop control of the Brushless DC machine.

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