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Design of a Brushless DC (BLDC) Motor Controller

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Abstract— Growing need for high productivity is placing new demands on mechanisms connected with electrical motors. The demand for low cost Brushless DC (BLDC) motor has increased in industrial applications. A simple BLDC motor control algorithm for low cost motor drive applications using general purpose microcontrollers has been created and presented in this paper. Proposed design will allow the user to rotate the motor either clockwise or counter clockwise direction. Depending on the rotor position the sensor will give response to the controller circuit. Then the controller circuit will fix the direction of current following to the stator. The design controller circuit is also implemented. The overall design consists of microcontroller circuit, logic gates, switching devices (MOSFET/BJT), BLDC motor, sensors.

Keywords— BLDC motor; Microcontroller; Sensor; BJT; MOSFET.

I. INTRODUCTION

The use of the permanent magnets in electrical machines in place of electromagnetic excitation results in many advantages such as no excitation losses, simplified construction, improved efficiency, fast dynamic performance and high torque or power per unit volume. The PM excitation in the early 19th century was not adopted due to the poor quality of PM materials. In 1932, the invention of Alnico revived the use of PM excitation systems, however it has been limited to small and fractional horse power dc commutator machines [1].

A brushless dc (BLDC) motor is a synchronous electric motor which is powered by direct-current electricity (DC) and which has as electronically controlled commutation system, instead of a mechanical commutation system based on brushes. In such motors, current and torque, voltage and rpm are linearly related.

In BLDC motor the electromagnets do not move, instead the permanent magnets rotate and the armature remains static. This gets around the problem how to transfer current to a moving armature. In order to do this, the brush systems assembly is replaced by an electronic controller. The controller performs the same power distribution found in a

brush dc motor, but using a solid state-static circuit rather than a commutator/brush system.

II. CONVENTIONAL BLDC MOTOR STRUCTURES

The construction of modern brushless dc motor is very similar to the ac motor, known as permanent magnet synchronous motor. Figure 1 illustrates the structure of a typical three phase brushless dc motor. The stator windings are similar to those in a poly phase ac motor, and the rotor is composed of one or more permanent magnets. Brushless dc motors are different from ac synchronous motors in that the former incorporates some means to detect the rotor position or (magnetic poles) to produce signals to control the electronic switches as shown in figure 2. The most common position/pole sensor is the hall element, but some motors use optical sensors [2].

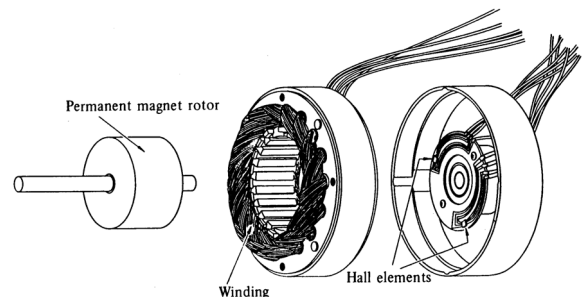


Fig. 1. Disassembled view of a brushless dc motor [2]

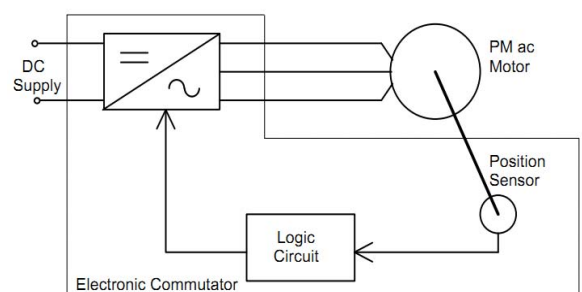


Fig. 2. Brushless DC motor block diagram

Although the most outerbox and efficient motors are three phases but two phases brushless dc motor are also very commonly used for simple construction and drive circuits. Figure 3 shows the cross sections of a two phase motor having axiliary salient pole [2].

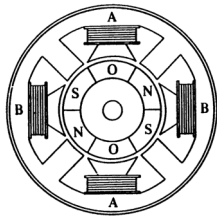


Fig. 3. Two phase brushless dc motor [2]

III. PROPOSED DESIGN OF BRUSHLESS DC MOTOR

The proposed design of brushless dc motor will made with two phases. The two phases are phase A and phase B. Considering the figure 4, for phase A the current is entering via FA and current leaving via SA. In the case of phase B current entering via SB and leaving via FB. If the two phase current in same direction then there is neutral pole will be created. If the two current are in opposite direction then there is a pole must be created. So in between SA and SB South Pole is created. As a result North Pole of the rotor will try to align with South Pole of the stator winding.

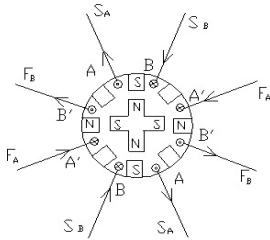


Fig. 4. Brushless DC motor

Now from the figure 5, for phase A the current entering is same of the figure 4. In case of phase B the current is entering via SB and leaving via FB. So the south pole will shift to the new postion in between SB and FA. Also in between SA and SB neutral pole will be created. So the rotor will try to align with this new postion. Hence the rotor will move clockwise 45 degree.

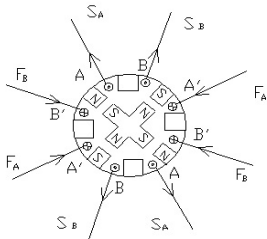


Fig. 5. Brushless DC motor (Phase A as before, Phase B reverse)

Taking account the figure 6, for phase B the current is entering is same of the figure 5. In case of phase A the current is entering via SA and leaving via FA. So the south pole will shift to the new position in between FA and FB. In between SB and SA neutral pole will be created. So the rotor will try to align with this new position. Hence the rotor will move another 45 degree. Now at this moment the total rotation is about 90 degree.

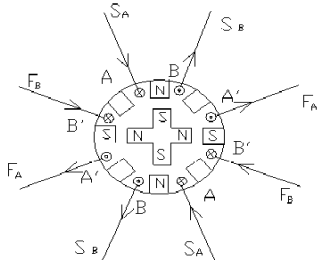


Fig. 6. Brushless DC motor (Phase A as reverse, Phase B as before)

Similarly in the figure 7, for phase A the current is entering as same of the figure 5. For phase B the current is entering via SB and leaving via FB. So the south pole of the rotor will shift to the new position. Hence the rotor will move clockwise another 45 degree. In this way the rotor will rotate clockwise.

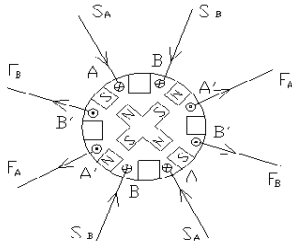


Fig. 7. Brushless DC motor (Phase A as before, Phase B reverse)

For counter clockwise rotation the sequence of the switching will be starts form figure7 then figure 6, figure 5, figure 4.

IV. STATOR CURRENT SWITCHING

The direction of the stator current will be controlled by using semi-conductor devices. The switches are may be MOSFET, BJT. In the figure 8 the positions of the switches are shown. Each phase connected with four switches. They are S1, S2, S3, and S4. In the figure 4, for phase A the current enter via FA and leaving via SA. So for phase A, considering the figure 8 switch S2 and S3 must be close and S1 and S4 must be open, in order to flowing the stator current from SB to FB. So the rotor will move 45 degree.

Similarly for figure 5, 6, 7 the respective switch of figure8 will turn on and off.

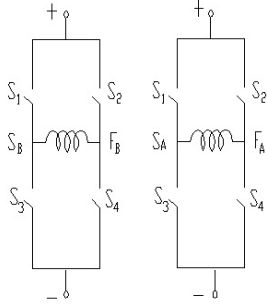


Fig. 8. Stator switching of phase B and phase A

Table I and Table II shows the switching of phase A and Phase B for various positions. The table exactly matches with the previous discussions of stator switching. For clockwise rotation the rotor moves from position 1 to position 4. For counter clockwise rotation the rotor moves from position 4 to position 1. The turn on of the switch represented as binary one and the turn off of the switch represented as binary 0.

TABLE I. FOR PHASE A(S_A-F_A)

Switch	Position 1	Position 2	Position 3	Position 4
S1	0	0	1	1
S2	1	1	0	0
S3	1	1	0	0
S4	0	0	1	1

TABLE II. FOR PHASE B(S_B-F_B)

Switch	Position 1	Position 2	Position 3	Position 4
S1	1	0	0	1
S2	0	1	1	0
S3	0	1	1	0
S4	1	0	0	1

According to table I, for phase A, the switch s2 and s3 are on for position 1 and position 2.And the switch s1 and s4 are on for position 3 and position 4.

According to table II, for phase B, the switch s1 and s4 are on for position 1 and position 4 and switch s2 and s3 are on for position 2.And the switch s1, s2and s3 are on for position 3.

TABLE III. SWITCHING SEQUENCE OF CLOCKWISE AND COUNTERCLOCKWISE ROTATION IN TERMS OF ANGLE(COMBINING TABLE I AND TABLE II)

Switch	0°	45°	90°	135°	180°	225°	270°	315°	360°
SA1	0	0	1	1	0	0	1	1	0
SA2	1	1	0	0	1	1	0	0	1
SA3	1	1	0	0	1	1	0	0	1
SA4	0	0	1	1	0	0	1	1	0
SB1	1	0	0	1	1	0	0	1	1
SB2	0	1	1	0	0	1	1	0	0
SB3	0	1	1	0	0	1	1	0	0
SB4	1	0	0	1	1	0	0	1	1

From table III,

- When the rotor position is 0 degree:

The switch s1 and switch s4 are off and switch s2 and s3 are on for A phase. The switch s2 and switch s3 are off and switch s1 and s4 are on for B phase.

- When the rotor position is 45degree:

The switch s1 and switch s4 are off and switch s2 and s3 are on for A phase. The switch s1 and switch s4 are off and switch s2 and s3 are on for B phase.

- When the rotor position is on the position is 90degree:

The switch s2 and switch s3 are off and switch s1 and s4 are on for A phase. The switch s1 and switch s4 are off and switch s2 and s3 are on for B phase.

- When the rotor position is on the position is 135degree:

The switch s2 and switch s3 are off and switch s1 and s4 are on for A phase. The switch s2 and switch s3 are off and switch s1 and s4 are on for B phase.

- When the rotor position is on the position is 180degree:

The switch s1 and switch s4 are off and switch s2 and s3 are on for A phase. The switch s2 and switch s3 are off and switch s1 and s4 are on for B phase.

- When the rotor position is on the position is 225degree:

The switch s1 and switch s4 are off and switch s2 and s3 are on for A phase. The switch s1 and switch s4 are off and switch s2 and s3 are on for B phase.

- When the rotor position is on the position is 270degree:

The switch s2 and switch s3 are off and switch s1 and s4 are on for A phase. The switch s2 and switch s3 are off and switch s1 and s4 are on for B phase.

- When the rotor position is on the position is 315degree:

The switch s2 and switch s3 are off and switch s1 and s4 are on for A phase. The switch s2 and switch s3 are off and switch s1 and s4 are on for B phase.

- When the rotor position is on the position is 360degree:

The switch s1 and switch s4 are off and switch s2 and s3 are on for A phase. The switch s2 and switch s3 are off and switch s1 and s4 are on for B phase.

In above discussions by changing the switching position of phase A and phase B of stator, user can change the rotor position

Figure 9 shows a wave shape by multiplying the common portion of the switching sequence. The wave shapes is required for designing the controller circuit. The wave shape described, for every position which switches will turn on and off.

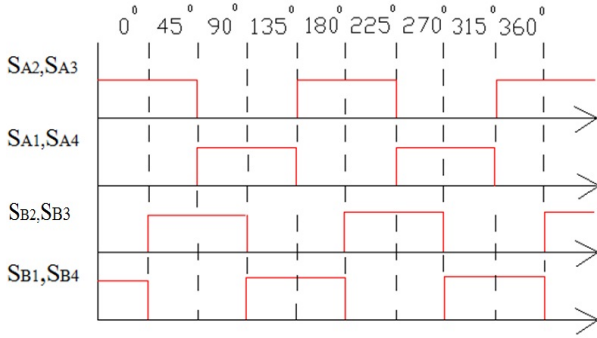


Fig. 9. Waveshape based on table III

TABLE IV. TRUTHTABLE OF SENSORS OUTPUT FOR CLOCKWISE AND COUNTER CLOCKWISE ROTATION

Degrees	C1	C2	C3	C4	CW/ CCW	A14	A23	B14	B23
0°	1	0	0	0	0	0	1	0	1
45°	0	1	0	0	0	1	0	0	1
90°	0	0	1	0	0	1	0	1	0
135°	0	0	0	1	0	0	1	1	0
180°	1	0	0	0	0	0	1	0	1
225°	0	1	0	0	0	1	0	0	1
270°	0	0	1	0	0	1	0	1	0
315°	0	0	0	1	0	0	1	1	0
360°	1	0	0	0	0	0	1	0	1
315°	0	0	0	1	1	0	1	1	0
270°	0	0	1	0	1	1	0	1	0
225°	0	1	0	0	1	1	0	0	1
180°	1	0	0	0	1	0	1	0	1
135°	0	0	0	1	1	0	1	1	0
90°	0	0	1	0	1	1	0	1	0
45°	0	1	0	0	1	1	0	0	1
0°	1	0	0	0	1	0	1	0	1

V. CONTROLLER DESIGN

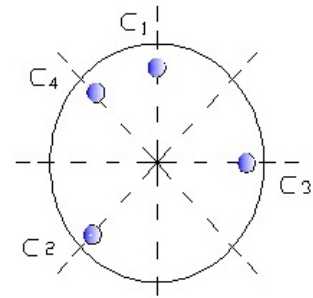


Fig. 10. Sensors position in our proposed design of BLDC motor

The four sensors C1, C2, C3 and C4 are attached to the BLDC motor as shown in figure 10. Let consider the tables IV, signals of sensors are coming from BLDC motor as input depending on the rotor position. Depending on that the controller circuit will control the stator current. In the table IV there is another signal called CW/CCW which will user define. That means user can control this signal. According to the table IV if the user will give 1(high) on CW/CCW pin then the rotor will rotate clockwise. If the user will give 0(Low) on CW/CCW pin then the rotor will rotate counterclockwise. Consider the figure 3.20 if the rotor is exactly on the position of Sensors C1. So C1 is interrupted, as a result of that C1 is high(logical 1), C2, C2, C3 are low. Now if the user will give CW/CCW is high (1) then the controller circuit will must give the signal of 45 degree to shift the rotor from 0 degree to 45 degree. So A23 and B23 are high, A14 and B14 are low according to the wave shape of figure 9. Similarly from 45 degree to 90 degree, 90 degree to 135 degree, 135 degree to 180 degree, 180 degree to 225 degree, 225 degree to 270 degree, 270 degree to 315 degree, 315 degree to 360 degree. For counterclockwise rotation, same switching sequence just user will give of CW/CCW low instead of high.

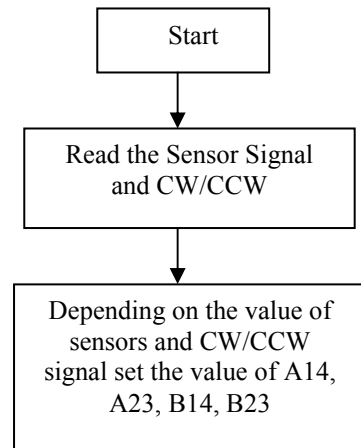


Fig. 11. Flow chart for designing the BLDC controller

A. Controller Design Using Digital Logic Circuit

The above controller circuit is done by using table IV. By derive the sum of product expressions the proposed controller circuit has been designed using DSCH-2 software. Here C1, C2, C3, C4 are coming from the sensors depending on the rotor position and CW/CCW is user define. It is actually used to control the clockwise and counter clockwise rotation. The output signal A14, A23, B14, and B23 are connected to the motor stator winding. Depending on the input signal the controller circuit will give output signal to control the clockwise and counter clock wise rotation.

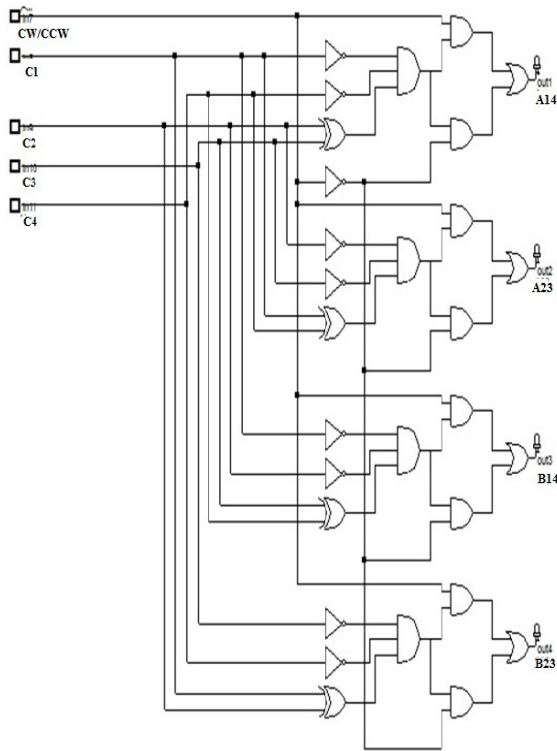


Fig. 12. Logic circuit based controller circuit

B. Controller Design Using Microcontroller

The microcontroller based controller circuit is done using Atmega 32 chip and simulated using proteus software. Though we have the limitations of getting sensors, the signal of the sensors is giving by mannual switches. We have the also limitations of getting brushless dc motor the stator winding is represented by light emitting diodes. The LEDs are used for showing the direction of current. In the main circuit the LEDs are replaced by stator winding of brushless dc motor.

Taking into account of figure 13, the four manual input c1, c2, c3, c4 represents the sensors which are connected with the motor. CW/CCW switch represents the users define input to rotate the motor clockwise and counter clockwise. When CW/CCW switch is on then the motor will rotate clockwise and when the switch is off then motor will rotate

counter clockwise. If the led is turn on that means the current will flow in the respective direction. Depending on the direction of current the magnetic pole will create in the stator windings. The stator winding is actually connected on the place of light emitting diodes.

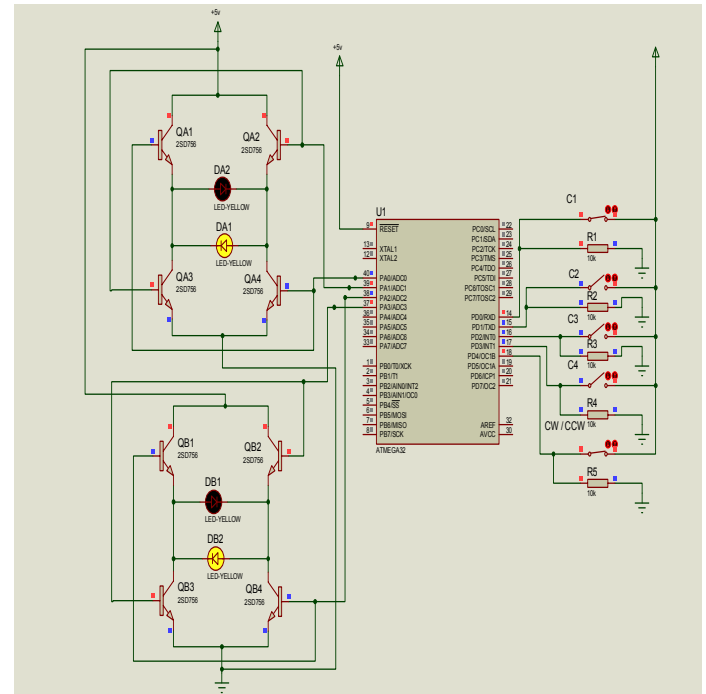


Fig. 13. Microcontroller based controller circuit

VI. SIMULATION AND RESULT

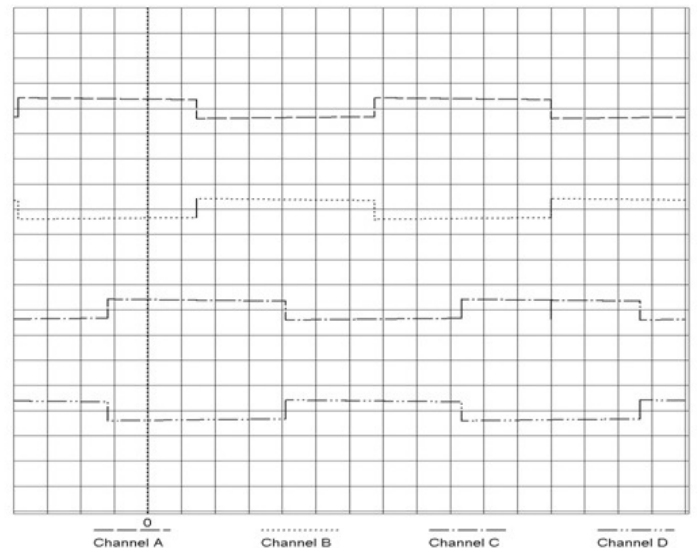


Fig. 14. Waveshape of the output of the controller circuit

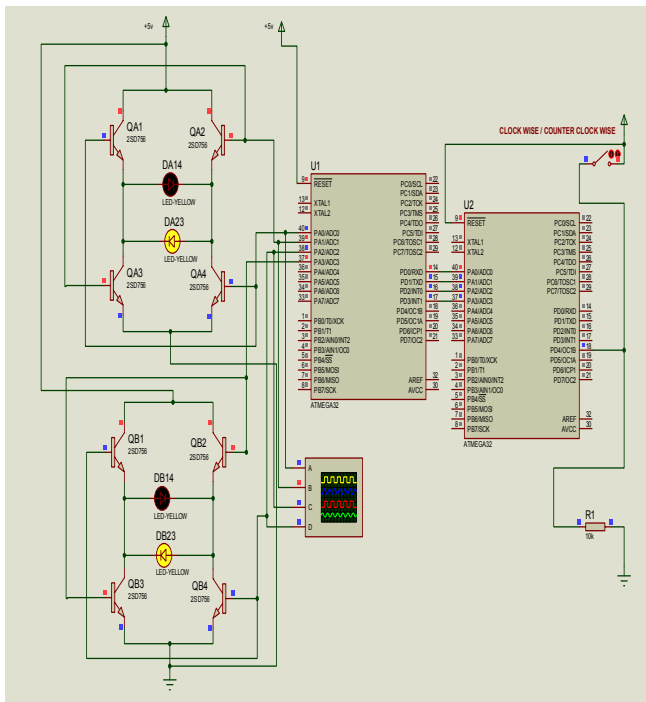


Fig. 15. Microcontroller based BLDC motor controller(Automatic input instead of sensor)

The wave shapes that shown in figure 14 is the output signal of the controller circuit A14, B14, A23, B23 which will drive the switching devices. The simulated waveshape exactly match with the theoretical waveshape of figure 9. The above waveshpes are found by using another microcontroller chip. The second microcontroller chip generates the sensor signal automatically. Practically the controller circuit get the sensor signal automatically depending on the rotor position.Due to the limitation of getting the sensor and motor, the sensor is replaced by microcontroller chip only for simulation purpose.Figure 15 shows the automatic sensor signal generator.

VII. COST COMPARISON OF TRADITIONAL BLDC MOTOR CONTROLLER WITH THIS PROPOSED CONTROLLER

The price of the brushless dc motor controller that is available in the market is \$ (14-18). Considering the following table:

TABLE V. COST OF THE DIFFERENT COMPTONS IN THE PROPOSED BLDC MOTOR CONTROLLER

Components	Pieces	Cost(\$)
MOSFET	8	\$ 1.5
Hall Sensor	4	\$ 3
Atmega 32 chip	1	\$ 2.90
PCB layout	1	\$ 1.25
		Total= \$ 8.62

Table V shows that the proposed BLDC motor controller has almost 50 percent less price compared to the conventional brushless dc motor controller.

VIII. CONCLUSION

A new algorithm for BLDC motor controller has been represented which is low cost and easier to understand. The modeling and analysis of brushless dc motor controller is done in microcontroller (AVR compiler, proteus) and logic gates generated in DSCH-2. The results of simulation give help in building hardware with expected results. The novelty of this proposed designed BLDC controller is that it is simple in terms of design, cost effective and can be implemented by using low cost microcontroller and ICs available in the market. In previous the entire BLDC controller that was design is expensive, difficult to understand. But the proposed controller is easier to understand and this is too much good to use in various application.

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