Implementation and Realization Of Brushless DC Motor

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Abstract— **Brushless DC motor (BLDC motors) also known as electronically commutated motors (ECMs, EC motors) are synchronous motors which are powered by a DC electric source via an integrated inverter/switching power supply, which produces an AC electric signal to drive the motor. Additional sensors and electronics control the inverter output amplitude, waveform and frequency. The motor part of a brushless motor is often a permanent magnet synchronous motor, but can also be a switched reluctance motor, or induction motor. Two key performance parameters of brushless DC motors are the Motor constants Kv and Km (which are numerically equal in SI units) Conventional dc motors are highly efficient and their characteristics make them suitable for use as servomotors. However, their only drawback is that they need a commutator and brushes which are subject to wear and require maintenance. When the functions of commutator and brushes were implemented by solid-state switches, maintenance-free motors were realised. These motors are now known as brushless dc motors. Halls Sensors sense the position of the coils. The Decoder Circuit turns appropriate switches on and off. The voltage through the specific coils turns the motor. It has various advantages like increased reliability, longer life,elimination of sparks, reduced friction. The torque characteristic of BLDC motor presents a very important factor in design of the BLDC motor drive system, so it is necessary to predict the precise value of torque, which is determined by the waveforms of back-EMF. The purpose of using of BLDC motor is that it saves atleast 50% of the energy as compared to the conventional motors and there is a marked reduction in manufacture cost. The BLDC motor is modelled using MotorSolve software provided by infolytica and all performance charts are extracted. The specification used is input voltage of 230V, 50Hz, input power is 45W@360rpm, output power is 25W@360rpm.**

Index Terms— EMI-Electromagnetic Interference, ECM- electronically commutated motors , EMF- Electromotive force,PM- Permanent Magnet

1 Introduction

Motor is basically a machine that converts electrical energy to mechanical energy. These may be bifurcated to ac motors and dc motors.The motor mainly consists of stator and rotor. Conventional dc motors are highly efficient and their characteristics make them suitable for use as servomotors. However, their only drawback is that they need a commutator and brushes which are subject to wear and require maintenance. Limitations of brushed DC motors overcome by BLDC motors include lower efficiency and susceptibility of the commutator assembly to mechanical wear and consequent need for servicing, at the cost of potentially less rugged and more complex and expensive control electronics. Commutator is cylindrical in structure, made of copper or carbon with high conductivity which are mounted on the rotor part of the brushed motor and helps to conduct current through conductor. When the brushes come to contact during rotation the electrical contacts to the rotating ring called *brushes*

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2 Basic Structure

BLDC motors are a type of synchronous motor. This means the magnetic field generated by the stator and the magnetic field generated by the rotor rotates at the same frequency. BLDC motors do not experience the “slip” that is normally seen in induction motors. BLDC motors come in single-phase, 2-phase and 3-phase configurations. Corresponding to its type, the stator has the same number of windings. Out of these, 3-phase motors are the most popular and widely used.

Brushless DC motors (BLDC motors, BL motors) also known as electronically commutated motors (ECMs, EC motors) are synchronous motors which are powered by a DC electric source via an integrated inverter, which produces an AC electric signal to drive the motor; additional sensors and electronics control the inverter output. A typical BLDC motor has permanent magnets which rotate and a fixed armature, eliminating the problems of connecting current to the moving armature.

An electronic controller replaces the brush/commutator assembly of the brushed DC motor, which continually switches the phase to the windings to keep the motor turning. The controller performs similar timed power distribution by using a solid-state circuit rather than the brush commutator system. The most common position/pole sensor is the Hall element, but some motors use optical sensors.

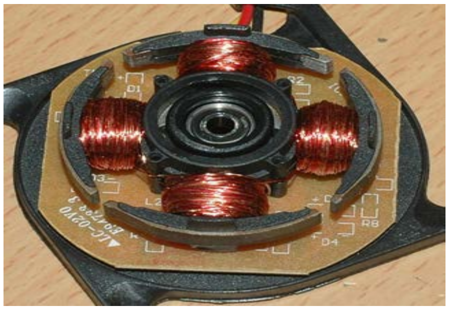


Fig.1.Basic internal structure.

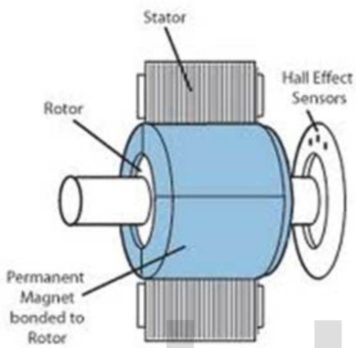


Fig.2a. Basic structure

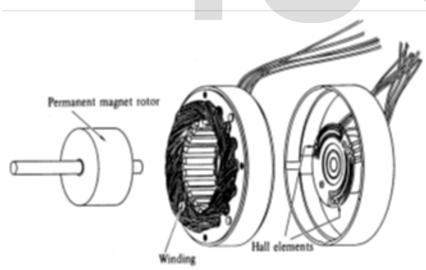


Fig.2b. Basic structure

3 COMPARISONS OF BRUSHED AND BRUSHLESS DC MOTOR

Although it is said that brushless dc motors and conventional Dc motors are similar in their static characteristics, they actually have remarkable differences in some aspects. When we compare both motors in terms of present-day technology, a discussion of their differences rather than their similarities can be more helpful in understanding their proper applications. When we discuss the functions of electrical motors, we should not forget the significance of windings and commutation. Commutation refers to the process which converts the input direct current to alternating current and properly distributes it to each winding in the armature. In a conventional dc motor, commutation is undertaken by brushes and commutator; in contrast, in a brushless dc motor it is done by using semiconductor devices such as transistors. Due to this BLDC offers a wide range of advantages which includes more torque per weight, more torque per watt (increased efficiency), increased reliability, reduced noise, longer lifetime (no brush and commutator erosion), elimination of ionizing sparks from the commutator, and overall reduction of electromagnetic interference (EMI). With no windings on the rotor, they are not subjected to centrifugal forces, and because the windings are supported by the housing, they can be cooled by conduction, requiring no airflow inside the motor for cooling. This in turn means that the motor's internals can be entirely enclosed and protected from dirt or other foreign matter. The maximum power that can be applied is limited by heat. The power can be applied till the insulation is not damaged. BLDC is much more efficient due to the absence of electrical and friction losses. The enhanced efficiency is greatest in the no-load and low-load region of the motor's performance curve.

The main disadvantage of BLDC is the cost of BLDC. The high cost is mainly contributed by the complex electronic speed controllers.

Table 1. Comparison of conventional and brushless DC motors

	Conventional motors	Brushless motors
Mechanical structure	Field magnets on the stator	Field magnets on the rotor Similar to AC synchronous motor
Distinctive features	Quick response and excellent controlability	Long-lasting Easy maintenance (usually no maintenance required)
Winding connections	Ring connection The simplest: Δ connection	The highest grade: Δ or Y-connected three-phase connection Normal: Y-connected three-phase winding with grounded neutral point, or four-phase connection The simplest: Two-phase connection
Commutation method	Mechanical contact between brushes and commutator	Electronic switching using transistors
Detecting method of rotor's position	Automatically detected by brushes	Hall element, optical encoder, etc.
Reversing method	By a reverse of terminal voltage	Rearranging logic sequencer

Fig.3. Comparision table between convetional and brushless DC motor

4 WORKING OF BLDC

The trick of operation in BLDC motors is the Hall sensor that is attached to the stator. It faces the magnets perpendicularly and can distinguish if the North or South pole is in front of it. As there is no commutator, the current direction of the conductor on the stator controlled electronically. Rotor consists the parmanent magnet where as stator consist a no. of windings. Current through these winding produces magnetic field and force. Hall sensor used to determine the position during commutation. The Hall sensor is this little component. When it senses the South pole, it keeps the coils turned off. When the sensor senses no magnetic field (or could be also the South pole), then it turns on the coils. The coils have both the same magnetic polarity which is North. So they pull the opposite pole and torque is then created. If we put a probe to a hall sensor then we will find a signal that during a full rotation the Hall sensor is two times HIGH and two times LOW(Fig.5).

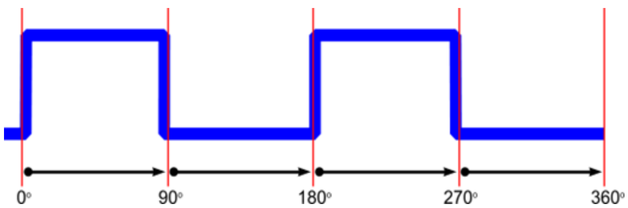
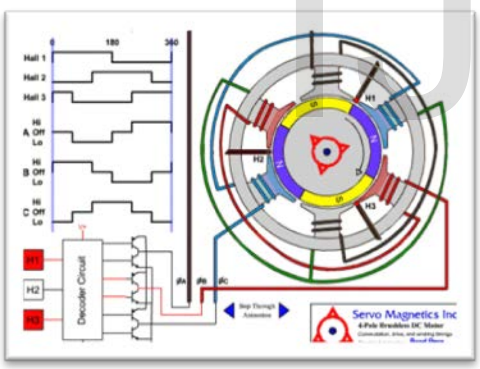


Fig.4. waveform on oscilloscope across Hall sensor

4 Internal Operation



Switching interval	Seq. number	Pos. sensors			Switch closed		Phase Current		
		H1	H2	H3			A	B	C
0° – 60°	0	1	0	0	Q1	Q4	+	-	off
60° – 120°	1	1	1	0	Q1	Q6	+	off	-
120° – 180°	2	0	1	0	Q3	Q6	off	+	-
180° – 240°	3	0	1	1	Q3	Q2	-	+	off
240° – 300°	4	0	0	1	Q5	Q2	-	off	+
300° – 360°	5	1	0	1	Q5	Q4	off	-	+

Fig.5. Phase sequence of current

Hall sensors sense the position of the coils. The Decoder Circuit turns appropriate switches on and off. The voltage through the specific coils turns the motor. Basically it operates in two-phase-on fashion, i.e. that two phase are energized which produce highest torque and the third phase is off. The energizing phase is depending on the position of rotor. At every 60 degree the signal from the position sensor produce a three digit number (H1, H2, H3). These three digit number decides the switch to be closed, which is shown in the fig.6.

5 BLDC Drive Model

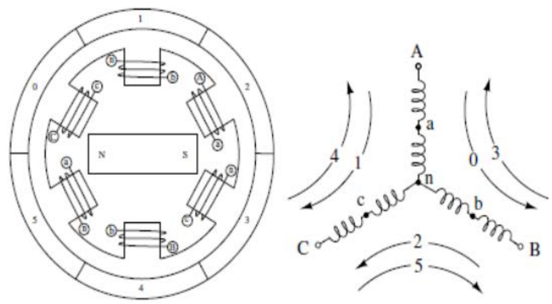


Figure 3.3: BLDC motor cross section and phase energizing sequence

An inverter is an electrical device that converts direct current (DC) to alternating current (AC); the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits. The phase energizing sequence is shown in the fig.3.3. Depending upon the Back EMF waveform: BEMF(U), BEMF(V), BEMF(W), the appropriate gates of the inverter are fired. Each gate in turned on for 60 degree interval. Thus there are 6 different firing sets to make what is called a '6 pulse generator'. The switching sequence depending upon the back emfs of the phase are shown in fig.8. Here Qi refers to the gate of the ith transistor being activated in the inverter.

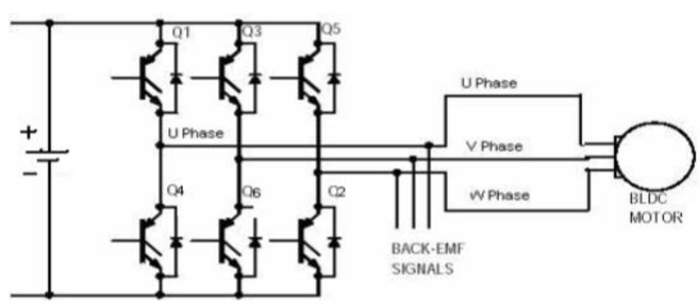


Fig.6.BLDC drive model

Variation of inverter output voltage due to change in firing angle is shown below:

El. Angle	Diode Current	$v_{ab} - e_{ab}$	$v_{bc} - e_{bc}$
$0^\circ - 60^\circ$	$i_c \neq 0$	$V_s - e_a + e_b$	$-e_b + e_c$
	$i_c = 0$	$V_s - e_a + e_b$	$\frac{1}{2}(-V_s + e_a - e_b)$
$60^\circ - 120^\circ$	$i_b \neq 0$	$-e_a + e_b$	$V_s - e_b + e_c$
	$i_b = 0$	$\frac{1}{2}(V_s - e_a + e_c)$	$\frac{1}{2}(V_s - e_a + e_c)$
$120^\circ - 180^\circ$	$i_a \neq 0$	$-V_s - e_a + e_b$	$V_s - e_b + e_c$
	$i_a = 0$	$\frac{1}{2}(-V_s + e_b - e_c)$	$V_s - e_b + e_c$
$180^\circ - 240^\circ$	$i_c \neq 0$	$-V_s - e_a + e_b$	$-e_b + e_c$
	$i_c = 0$	$-V_s - e_a + e_b$	$\frac{1}{2}(V_s + e_a - e_b)$
$240^\circ - 300^\circ$	$i_b \neq 0$	$-e_a + e_b$	$-V_s - e_b + e_c$
	$i_b = 0$	$\frac{1}{2}(-V_s - e_a + e_c)$	$\frac{1}{2}(-V_s - e_a + e_c)$
$300^\circ - 360^\circ$	$i_a \neq 0$	$V_s - e_a + e_b$	$-V_s - e_b + e_c$
	$i_a = 0$	$\frac{1}{2}(V_s + e_b - e_c)$	$-V_s - e_b + e_c$

Zero Crossing' block evaluates the zero crossings of:
1. UV: zero crossing detection of BEMF U – BEMF V
2. VW: zero crossing detection of BEMF V – BEMF W
3. WU: zero crossing detection of BEMF W – BEMF U

These signals can be used to synchronize the controller or the inverter.

'120 deg trigger' block is used to hold the controller to its initial state till the time motor picks up sufficient speed and the back emf voltages are significant. It is to be noted here that sensorless control design has been implemented, which depends heavily on the values of the back emfs. Initially, since the motor is at the standstill, the back emfs have not built up.

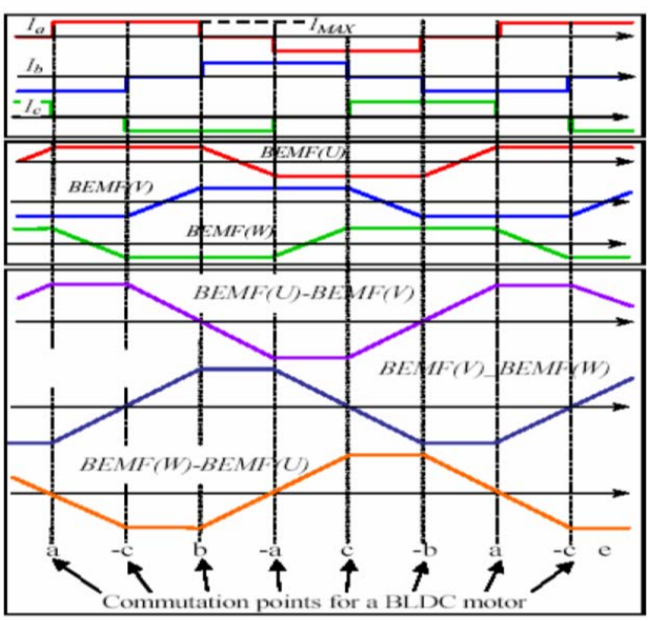


Fig.7. sequence waveform.

Thus the motor is 'blindly' ramped up till sufficient voltages are built up. It is important that during this period the controller does not lose its initial state. More about the ramping is describe in the '120 deg trigger' block.

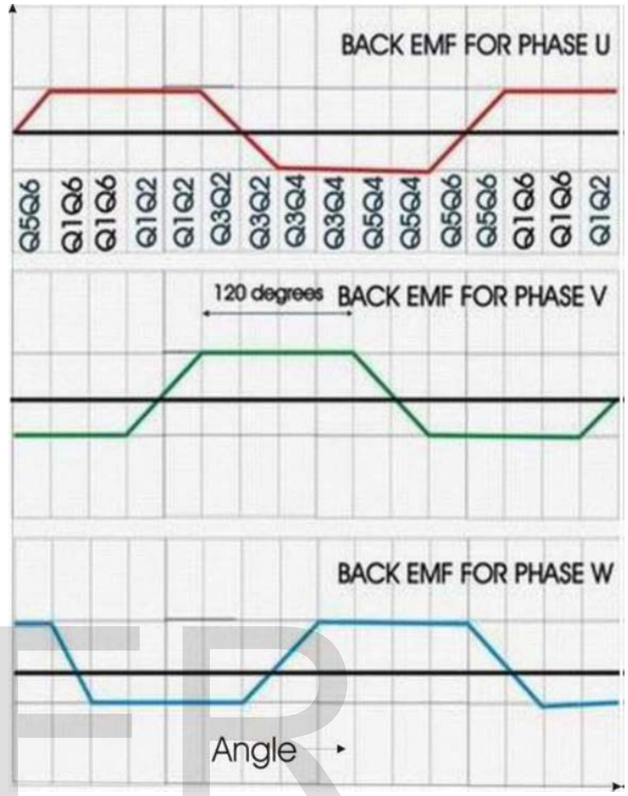


Fig.8. back emfs and the switching sequence.

'120 deg trigger' block ramps up the motor for some time determined by the value in the field 'threshold time' in the block 'CHANGER'. After Threshold time the block 'CHANGER' just disconnects the '120 deg trigger' block and puts the motor in the closed loop. The sequence followed by the '120 deg trigger' block is Q5Q6-Q1Q6-Q1Q2-Q3Q2-Q3Q4-Q5Q4. The above pattern is followed in the 120 degree mode of excitation, hence the name '120 deg trigger'. The switching sequence waveform with back emf is shown in fig.9.

6 MODELING OF BLDC MOTOR IN MOTOR SOLVE

Specifications:

Based on the specification given in the table (fig.9), a prototype model of brushless DC motor in motor solve software is designed. The model is shown in fig.10. MotorSolve BLDC calculates machine performance based on automated finite element analysis. The finite element method is a computational scheme to solve field problem in engineering and science. The technique has a very wide application, and has been used on problems involving stress analysis, fluid mechanics, heat transfer, electrical and mechanical field, etc. It has various advantages like it can handle loading/boundary condition, time dependent, and also we can include the dynamic effect. After modelling of BLDC motor, various characteristics graph were drawn in motorsolve and were discussed below.

TABLE I. Dimensions and properties of the prototype motor

PARAMETER	SYMBOL	FIGURE
Number of phases	m	3
Number of poles	p	4
Number of slots	Q	12
Airgap	g	0.5 mm
Rated torque	T	0.4 Nm
Airgap flux density	B_g	~ 0.4 T
Rated speed	ω_m	7500 RPM
Back-EMF	E_{ph}	11.9 V
Rotor diameter	D_r	20 mm
Airgap diameter	D	22.5 mm
Stator inner diameter	D_{is}	23 mm
Stator outer diameter	D_{os}	52.8 mm
Tooth width	b_{ts}	3 mm
Rotor back height	h_{yr}	4.4 mm
Stator back height	h_{ys}	4.4 mm
Magnet thickness	l_m	1 mm
Copper area	A_{cu}	~ 32.5 mm^2
No. of conduc. / slot	n_c	28
Slot height	h_s	10 mm
Active motor length	L	30 mm
End winding length	L_{end}	9 mm
Current density	J	~ 10 A/mm^2
Max. temperature	T_{max}	~ 61.2 °C
Diameter of conduc.	$A_{conductor}$	1.1 mm
Current loading	S_1	47.5 kA/m
Max. current loading	S_{max}	85.1 kA/m
Centrifugal force on magnets	$F_{centrifugal}$	7.6 N
Mass of copper	M_{copper}	~ 170 g
Mass of magnet	M_{magnet}	~ 144 g
Mass of iron	M_{iron}	~ 310 g

Fig.9. Specification used in Motor Solve.

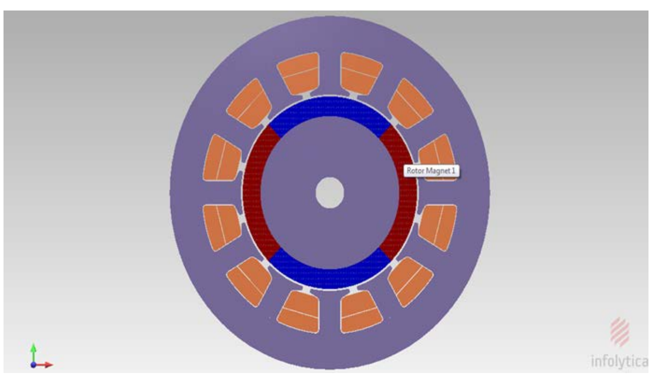


Fig.10. Prototype model.

7 Results of the Design

Fig.11 shows the distribution of flux density within the motor. From figure we can see that the flux lines associated with one pole are not intersected by any other lines. Fig.12 shows the characteristic graph between current with respect to position, whereas Fig.13 and Fig.14 shows the graph between back emf and flux density with respect to position. From Fig.15 we can see that torque remain constant up to certain speed and then it decreases as speed increases. But when we plot a graph between torque and source angle, it oscillate (Fig.17). Cogging torque of electrical motors is the torque due to the interaction between the permanent magnets of the rotor and the stator slots of a Permanent Magnet (PM) machine. It is also known as detent or 'no-current' torque. It is prominent at lower speed (Fig.16).

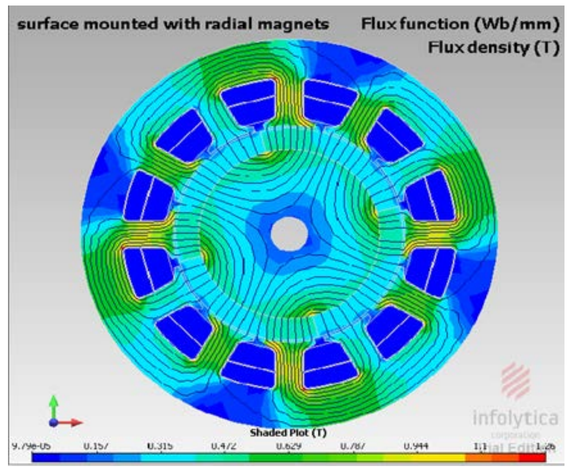


Fig.11. Flux density distribution

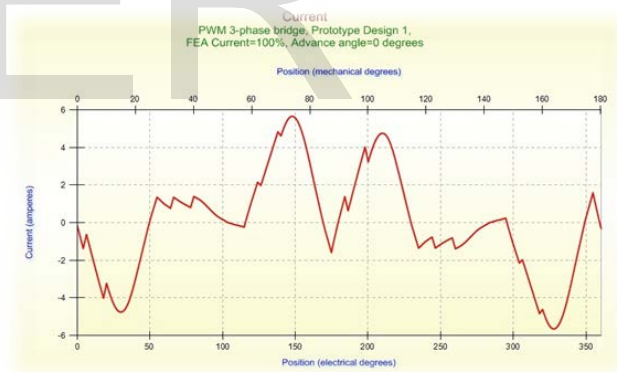


Fig.12. Current vs position(electrical degree)

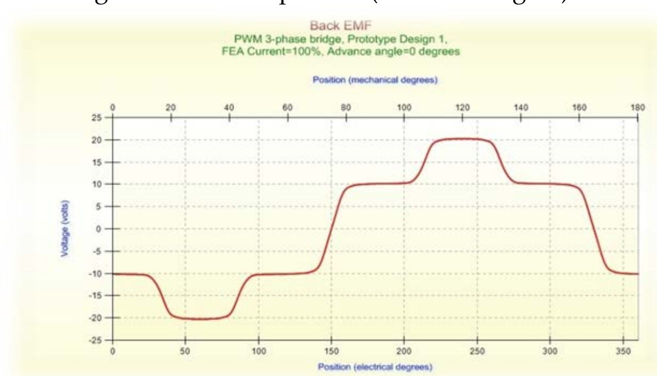


Fig.13. BACK EMF vs. POSITION (electrical degree)

Fig.14. FLUX DENSITY vs. POSITION (electrical degree)

Fig.15. TORQUE vs. ROTOR SPEED

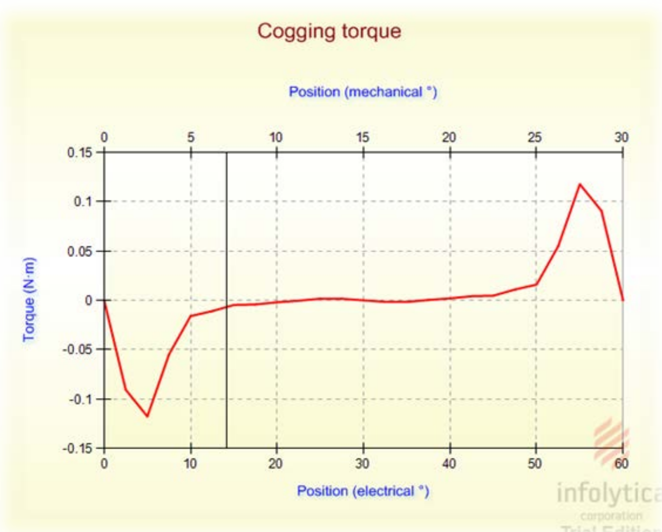


Fig.16. Cogging torque

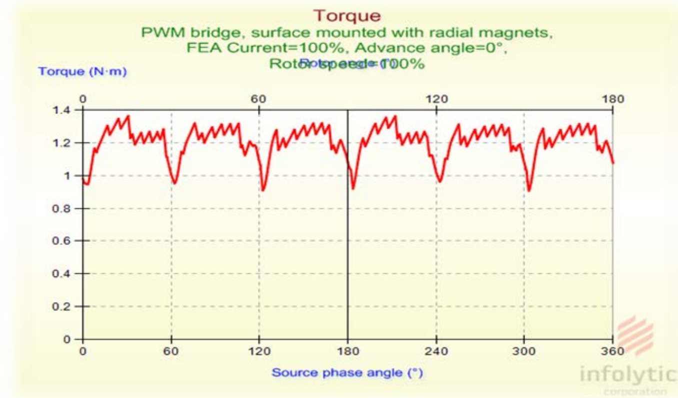


Fig.17. Torque vs. Source angle

Conclusion

For the present world, BLDC motors are the most efficient motor for any application. We made a prototype model of BLDC motor and go through different characteristics graph, and we conclude that it is the most reliable and efficient compare to other. It has longer life and reduces friction losses and eliminated spark from commutator.

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