Development of a Novel Transmission System for Electric Vehicle

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Abstract

For energy saving capability, sustainability and zero emission electric motors earned a significant demand in electric vehicles. Outer rotor BLDC motors became alternative to regular DC brushed permanent magnet motors as it requires low power consumption and fewer costs. To reduce the electrical drive loss in electric vehicles the rotary part of the outer rotor BLDC motor is directly adjusted to the wheel. In this work the rotor directly acts as a wheel of a three wheeler and the rpm changes with the input direct current. Rotor working as a powered wheel eliminates the conventional transmission chain used in ICE car thus prevents the mechanical loss for transmission. From the output characteristics of the system the torque and speed behavior, current and produced torque relation based on load torque, output power and efficiency behaviors were investigated. Structural simplicity was obtained due to absence of rotor winding, brushes and coupling mechanism.

Keywords: Brushless motors, Outer rotor BLDC, permanent magnet motors, motor losses.

1. Introduction

We are passing an outstanding era of automobiles. Things became easier and more dynamic than before. Hybrid and electric cars demand more attention than internal combustion engine cars because of operational flexibility and greater efficiency. A stationary stator winding, a rotor with permanent magnets, driver circuits and position sensing hall sensors constitute a brushless direct current (BLDC) motor. In outer rotor BLDC motor the rotary part rotates outside the stationary winding. A controller unit helps exciting the regarding motor phase based on the rotor position data and the direction of rotation. The brushless motors' rotor wheel with the permanent magnet mounted on acts directly as the wheel of the vehicle without any requirement of motion transfer organ. Higher efficiency is obtained due to lack of any mechanical transfer loss. This eliminates the conventional transmission system of the ICE cars.

Outer rotor BLDC motors are specially intended for the applications which require motors of short stack length and long external diameters. Outer rotor BLDC motors have greater magnet surface allowing larger air gap which leads to mechanical tolerances.

Carried out literature surveys showed no specific studies about using the rotor wheel of BLDC directly as the wheel of a vehicle. However studies regarding this topic are summarized below. D.J Patterson highlighted the reason to use BLDC for vehicular purpose and described the use of finite element technique in their design [1]. For electric vehicle, T. Chan et al. favored axial flux motor more than the radials [2]. S. Wu et al. analyzed ways to improve the performance of permanent magnet (PM) wheel motors [3]. They analyzed the performance of the motor in four aspects: magnetization direction and pole number; no-load air-gap flux density; no-load electromagnetic force (EMF); and flux insulation. Lopez- Fernandez et al. designed an outer rotor BLDC for light traction at low rates using finite elements method (FEM). To observe the designed motor's performance rate, phase current, power and torque curves with respect to time were assessed [4]. YP Yang et al. studied about a current distribution control on dual direct-driven wheel motors for electric vehicles. The vehicle dynamics and control strategy were modeled and the control performance was simulated numerically [5]. Y. Honda et al. studied interior permanent magnet synchronous (IPM) motor [6].

This study showed prototyping a three wheeler driven by an outer rotor BLDC motor by means of using the rotary part directly as a wheel of the vehicle. After fabrication performance evaluation was investigated and the results are shown in this paper.

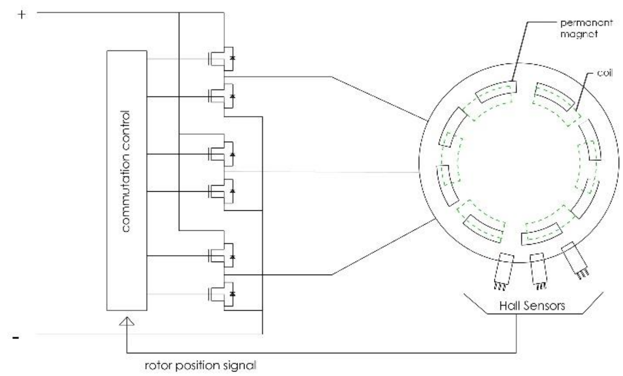

Fig. 1. Diagram of an outer rotor BLDC motor drive.

2. Drive description

A brushless DC motor is a permanent magnet synchronous electric motor which is driven by direct current (DC) electricity and it accomplishes electronically controlled commutation system. BLDC motors are also referred as trapezoidal permanent magnet motors. BLDC motor works on the principle of the Lorentz force law which states that whenever a current carrying conductor placed in a magnetic field it experiences a force. As a consequence of reaction force, the magnet will experience an equal and opposite force. Motor operation is based on the attraction or repulsion between magnetic poles. Using the three-phase motor shown in Figure 1, the process starts when current flows through one of the three stator windings and generates a magnetic pole that attracts the closest permanent magnet of the opposite pole. The rotor will move if the current shifts to an adjacent winding. Sequentially charging each winding will cause the rotor to follow in a rotating field. The torque depends on the current amplitude and the number of turns on the stator windings, the strength and the size of the permanent magnets, the air gap between the rotor and the windings, and the length of the rotating arm. Star connection was used as it has simpler commutation logic which is less prone to bridge shortening [7]. Hall-effect sensors were being used for low cost, low resolution requirements and optical encoder for high resolution requirements [8].

3. Motor parameters and motor losses

Motor voltage constant (K_e): Motor voltage constant is the ratio of constant supply voltage and the speed.

$$K_e = \frac{volts(v)}{Speed(rpm)} \quad (1)$$

Motor torque constant (K_t): Motor torque constant expresses how current relates to torque. It is the ratio of torque and the supplied current.

$$K_t = \frac{K_e}{0.00684} \; \frac{lb-in}{amp} \quad (2)$$

Developed Torque: Torque developed at rotor is directly connected to the direct current supply and is determined by the following equation:

$$M_o = I \times K_t \quad (3)$$

For a given load torque the speed in rpm can be calculated as follows

$$rpm = T \times \frac{N_o}{M_H} \quad (4)$$

Where, N_o is no-load speed (rpm) and M_H is the stalling torque (Nm).

Copper losses (P_{cu})

Copper losses are an undesirable transfer of energy, as are core losses, which result from induced currents in adjacent components. Copper losses are calculated by the following equation [9]

$$P_{cu} = 3K_\theta \times I_{RMS}^2 R \quad (5)$$

Where K_θ is the temperature correction factor and R is the resistance (Ω) calculated by the following equation:

$$R = \rho \times \frac{L}{A_{cond}} \tag{6}$$

And $I_{RMS} = 0.816I$; I is the DC current (A) input.

Mechanical losses [10]

This type of losses are subdivided into two parts: friction losses (P_f) and windage losses (P_w).

$$P_m = P_f + P_w \tag{7}$$

Friction losses can be determined by the equation:

$$P_f \approx \frac{3}{2} n_r G_r N \times 10^{-3} \tag{8}$$

Where, n_r= No. of bearings
G_r= weight of the rotor and
N= Speed in rpm.

The windage losses are calculated as through:

$$P_w \approx 2D_{out}^3 LN^3 \times 10^{-6} \tag{9}$$

Where, D_{out}=rotor's outer diameter (m)
L= rotor's length (m)

4. Design consideration

Three phase star connection was taken. For prototyping the structure was thought easy enough for manual construction. Pair of poles were kept in less amount to avoid problems in manual winding. The fabricated BLDC was planned to mount on a small three wheeler and therefore the rotor wheel diameter was taken as 85 millimeters. For maintaining 15 millimeters ground clearance the stator diameter was assumed 70 millimeters and based on this assumed dimensions 8 permanent magnet was placed on the rotor wheel. Air gap was kept 3 millimeters as manual construction lacks in precision. Calculating the circumference the magnets were aligned with an angle of 0.29 radian.

Table 1. Initial design consideration

Pair of poles	3
No. of phase	3
No. of permanent magnet	8
Air gap length	3 mm
Rotor Outer diameter	85 mm
Stator inner diameter	70 mm
Magnet degree	0.29 rad

For the motor the supply voltage was 11.7 volt and it varies a bit sometimes. The phase resistance was measured by a multimeter. Copper wire used for winding was 21 gauge standard. Number of turns were assumed to be 60 per coil.

Table 2. Machine data

Phase resistance	2Ω
Phase self-inductance	0.15 H
DC supply voltage	11.7 V
No. of phases	3
No. of turns per coil	60

Assembly of the stator and the rotor with permanent magnet is shown in fig. 2.

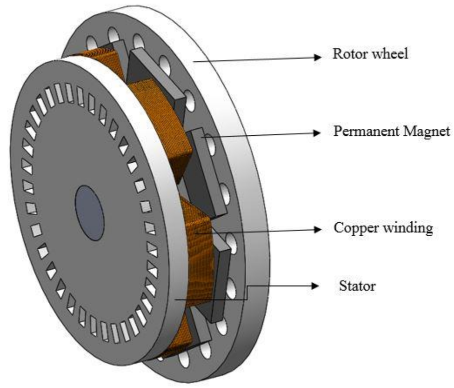

Fig.2. Assembly of rotor and stator

5. Fabrication

3D Printing of Rotor & Stator
↓
Winding of Copper Coil in Stator
↓
PM Placement in the Rotor
↓
Wye Connection to the Winding
↓
Connection of Hall Sensor
↓
Stator rotor Assembly
↓
PCB Board Design & printing of Circuits
↓
Connection According to the Circuit Design

Fig. 3: Fabrication process

Following the design the rotor and the stator parts were 3-D printed. The stator part has six poles and the 21 gauge copper wire was used for winding. The winding followed the wye connection. The rotor has 8 permanent magnet mounted on it. After printing the PCB board following the Proteus circuit design connections were done carefully. The hall sensors were placed to know the rotor position and passes the positional signal to the controller unit. Based on the signal the MOSFET helps flowing required amount of current to the winding. The speed measurement hall sensor module acts as a tachometer.

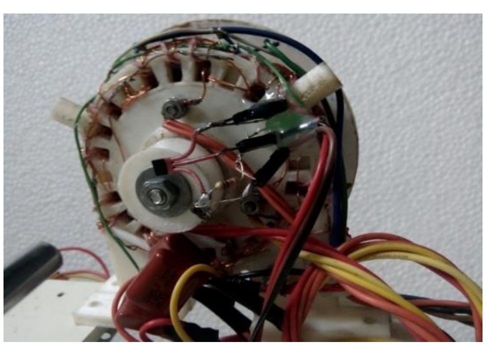

Fig. 4. Fabricated BLDC motor prototype

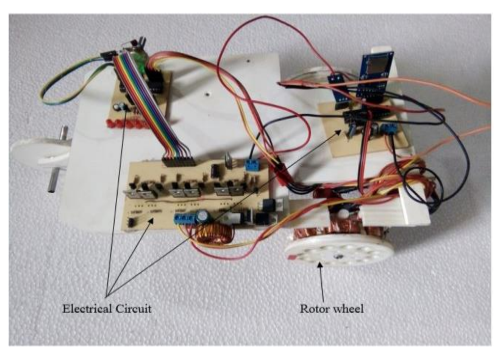

Fig.5. 3-wheeeler model with BLDC mounted as the wheel

6. Results and discussion

In the figure 6 the output speed is shown against the applied load torque. Toque developed is also shown on the secondary axis. In the figure 6.1 with the increase in load torque the speed reduces. When the load torque was minimum of 0.26 Nm the speed was highest 679 rpm. And when the load torque was increased to 6.56 Nm the speed reduced to minimum 43 rpm. On the other hand the developed torque increases with the applied load torque. Produced torque due to the input current remains greater than the load torque.

In the figure 7 the input direct current increases with the increased torque. The speed is inversely proportional in general, however the speed versus torque curve wasn't obtained perfectly linear but a reverse relation is obtained which implies similar characteristics to general case. The power output is first increased and after increasing the torque to 4.8Nm the output power decreased. And the efficiency increases with the torque and after a certain torque it started to decrease.

Two major losses in the prototype, copper losses and mechanical losses, were calculated. The relation between the losses with current input is shown in figure 8. When the rpm was increased gradually the losses started to increase. Among the losses the copper losses possessed the significant portion about 8-12%.

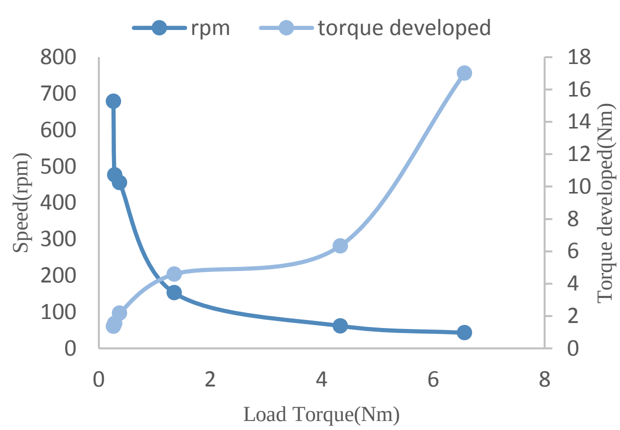

Fig. 6: Speed, torque developed versus load torque curve

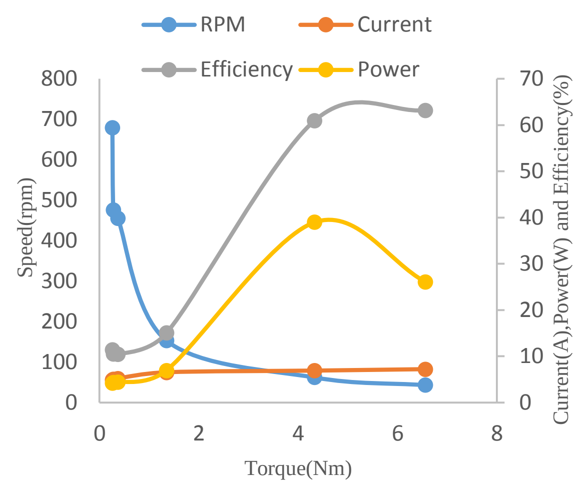

Fig. 7: Comparative demonstration of calculated parameters from data taken from the prototype

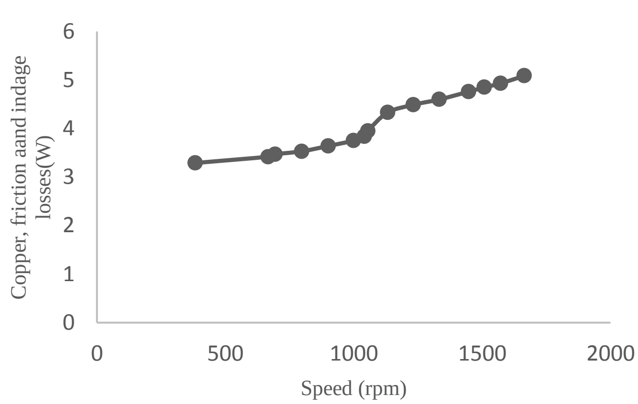

Fig. 8. Copper, friction and windage losses' characteristics against speed

The prototype obtains maximum efficiency around 60%. A significant amount of loss occurs due to the higher air gap and manual construction. The stator winding can't be precisely completed due to manual process. Also the rotor and stator's base weren't iron or any other metal and so this hampers the better efficiency and power losses occurred. Stator winding and permanent magnet were placed on the 3-D printed structure of plastic. As no shaft was used for transmitting the produced torque, no drive loss occurred in this context. If the construction meets the precise procedure and better metal conductor the efficiency will be increased and eliminate the undesired loss in efficiency.

7. Conclusions

In this work an outer rotor BLDCs rotary part is proposed to be used as a wheel of a vehicle. In existing IC engine vehicles a huge portion of energy produced by burning of fossil fuel is lost during the long transmission pathway. To eliminate the carbon emission, to prevent the transmission loss and for simpler transmission electric vehicle appeared. But EVs drive loss from the induction or synchronous motor is a hindrance to attain better and efficient drive condition. This proposed system eliminates the transmission chain seen in conventional automobiles thus the transmission loss is prevented. Conventional automobiles get bulky for the heavy IC engine and its transmission equipment. Vehicles with outer rotor BLDC are light in weight. The characteristics of the input and output parameters showed in chapter 6 imply better condition and well run system. The curve behaviors obtained are quite satisfactory. Greater scale model may suit on any three wheeler within low power consumption. With the increased load condition the prototype provided good response drawing more current. In case of full scale installation the requirement will change and for better performance some changes in the material of conductor and in design may need attention like rotor material, poles of stator winding, permanent magnet selection etc. With this proposed transmission system the vehicles sustainability will be increased. Less drag will be produced for being lighter than conventional automobile. As power requirements are lower for BLDC greater efficiency may be attained if precise design can be achieved.

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