

Electric Two-Wheeler BLDC Hub Motor Design, Modeling, and Performance in Real-Time Use



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Abstract The push on electric mobility given by the government of India gained a lot of importance in the recent years with a subsequent growth in the electric vehicles especially two-wheeler focused. This brings an urgent need for the improvement of performance criteria in electric vehicles. Although electric vehicles are more efficient than conventional vehicles, the parameters like the efficiency of the electric motor, torque measurement, back emf, and speed of the electric vehicle and motor are to be continuously evaluated to hold the electric vehicles place at the top. In this paper, a deep research was done on the performance of a BLDC hub motor in both simulation and real-time application usage. As the stator and rotor of a brushless direct current motor play a vital role in deciding the performance, they were designed and later the modeling was done for the same using MATLAB and Simulink and the results are then compared to the experimental setup made for the torque measurement at corresponding speed, currents, and voltages.

Keywords BLDC Hub motor · Electric vehicle · Motor Torque · Performance

1 Introduction

The expansion of mid-range horsepower engines in the markets exceeds that of smaller fractional horsepower motors. The heating and cooling equipment industries are driving this demand, along with electric vehicles, which will provide the best growth opportunities. Demand is seen in all systems, from automotive, avionics, military, and space to increase performance and reduce weight. Along these lines, a

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directive to increase motor performance has been released by the European markets. The military and avionics markets worldwide are also powered by decreases in size and increases in operational and ownership costs. More stable and effective engines and control techniques must be considered to accomplish these objectives. As this market continues to expand, on the basis of its reliability, performance, and scale, the brushless DC motor is the most sensible option.

In terms of other engine types, the BLDC motor offers strong advantages in terms of performance and size optimization in challenging motor applications. BLDC engines do not have brushes and need less downtime for maintenance and the system. Yet these engines require electronic controllers ranging from basic to complicated. Usually, the engines are over 80% powerful and the controls are in the 95% range [1]. Thus, the enabling technology is the BLDC motor controller's ever-improving evolution. Pulse Width Modulation (PWM) sampling is used by the most powerful controllers to drive a DC power motor [2]. There are also other criteria for power conditioning that range from rectification of an AC signal to filtering for electromagnetic interference (EMI) that is required in most applications.

A review was conducted on the performance where the controller strategy had the highest relative importance among other requirements. Motor performance came second in the importance list which plays a vital role among the powertrain components in the vehicle design [3]. The amount of power needed for the bike should be determined considering the environmental conditions [4]. A simulation environment was built and the target system was modeled in order to analyze the driving performance [5]. Research on improving motor efficiency is done intensively [6].

2 Methodology

In this paper, in order to find the performance characteristics of a bldc hub motor in simulation and real-time use, various tests were conducted to satisfy the problem statement. They include the speed control of bldc hub motor, torque measurement, and efficiency of the motor. The experiment was not limited to a single bldc hub motor, instead it was performed with multiple motors to validate the actual performance test bed of the motor. To perform these activities, first the stator and rotor of a bldc hub motor with 1000-W capacity were designed in JMAG designer providing all the required input data as per the existing 1000-W motor which can operate at 48 V (Figs. 1 and 2).

3 Torque Measurement

Although, the torque of a motor can be measured by using a torque sensor, in this article the torque estimation and measurement experiment was performed by the physical experimental setup using a brake test. This reduces the overall cost of the

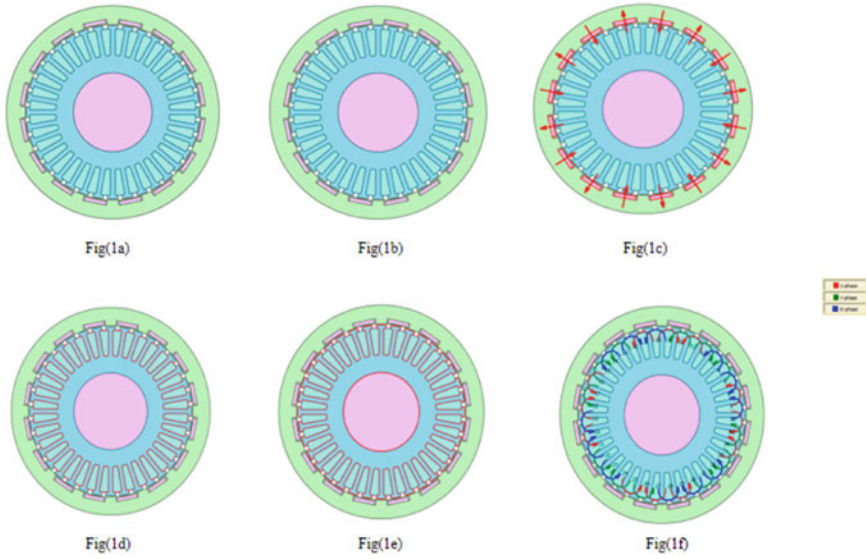


Fig. 1 a Motor diagram. b Rotor core. c Rotor magnet. d Stator coil. e Stator core. f Winding

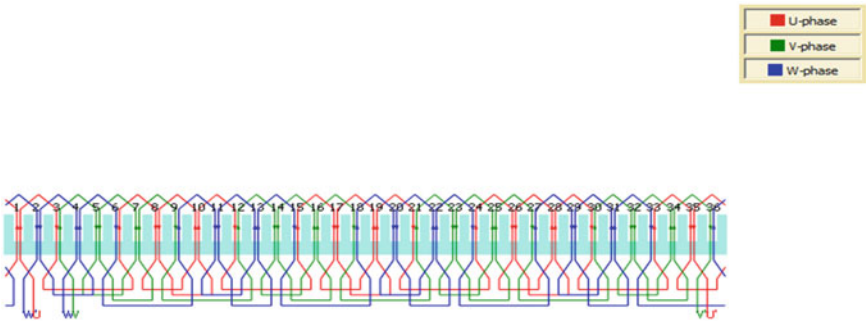
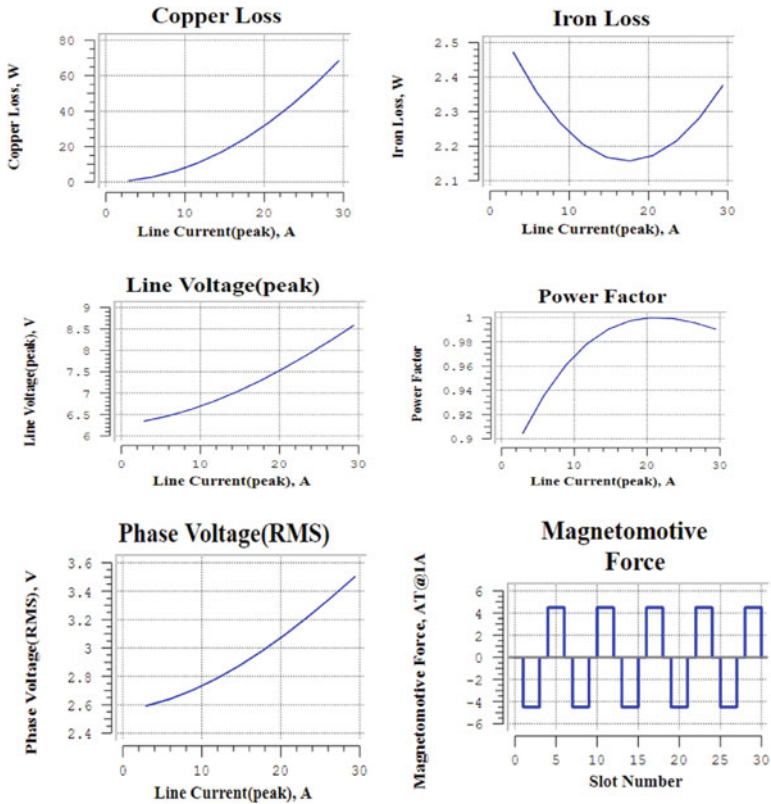


Fig. 2 Slot diagram

project with a minimal error in the output. The motor torque was measured by a spring balance and load in the rope test. The rope test was carried by varying loads such that the weights which act like a load are considered according to the load on the motorbike. The load on the bike was considered as a single rider with an average weight of 60 kg, and also with a ride pillion. The weight of the rider and pillion was considered to be 120 kg. In this test, the load was varied between 60 and 120 kg so that there will not be any discrepancy when the weight of the rider or pillion got changed.

4 Results and Discussion

4.1 Design Results



4.2 Simulation Results

The proposed comparison can be obtained by comparing the actual results obtained in the real-life use to the simulation results. While modeling this, not only the torque of the motor but also parameters like back emf, speed, and current were also simulated, and the corresponding torque for a particular speed, current, and back emf was observed. This provides the additional information to the reader about the requirements of all the parameters at a particular instant of torque (Fig. 3).

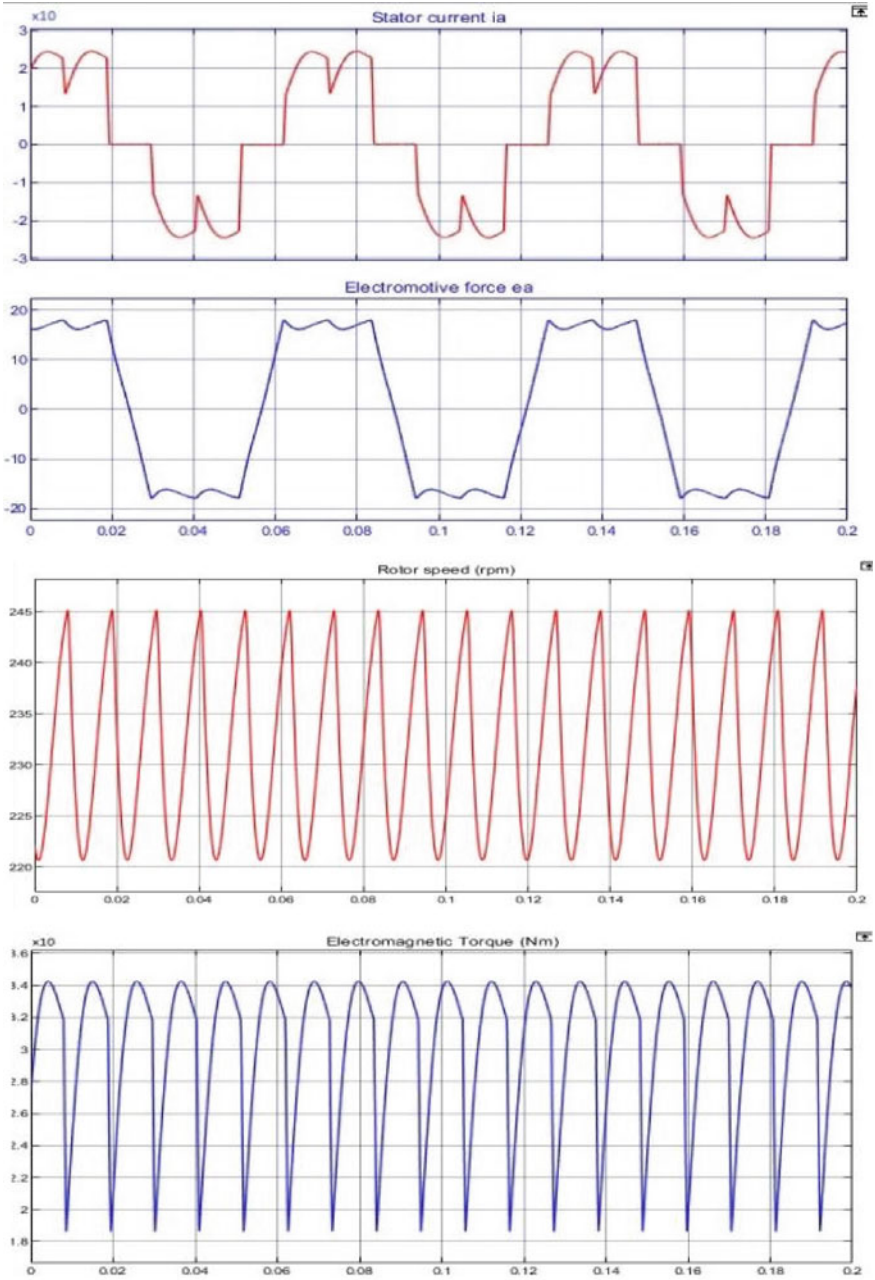


Fig. 3 Simulation results of Simulink model

Since mechanical power is the product of torque and RPM, no power is generated when there is no torque or rotation. Also, the output power of the motor is less than the input power due to heat losses.

4.3 Power Flow

Figure 4 below shows the power flow of a dc motor in which a major amount of power is being wasted in terms of various losses. So, to minimize these losses, a proper design of the motor comes into play.

The above results are used to find out the efficiency of the motor considering the obtained losses and plotted (Fig. 5).

$$K_c = 0.8;$$

$$K_i = 0.1;$$

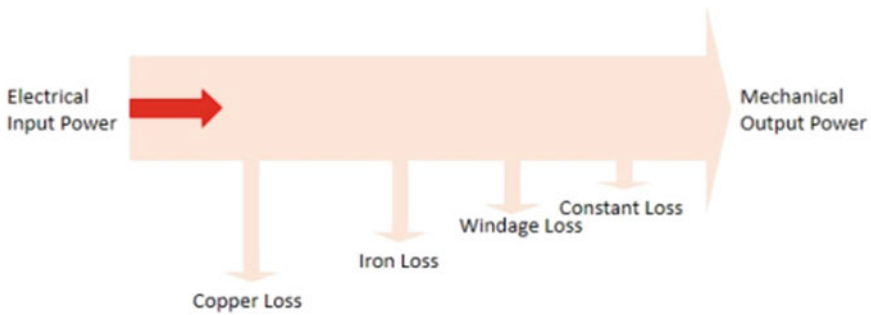
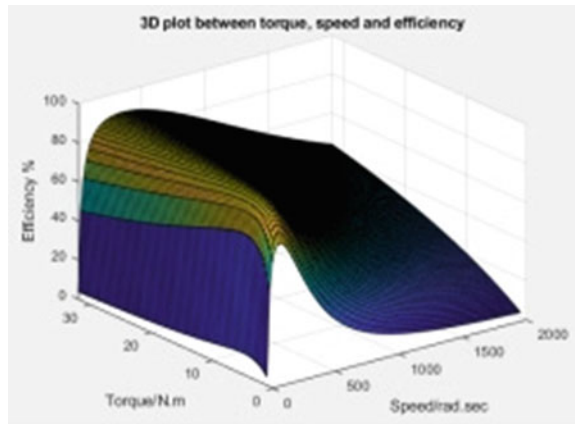


Fig. 4 Power flow

Fig. 5 Efficiency plot wrt Torque and speed



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Kw = 0.00001;
Cl = 20;
x = linspace(1,2000);
y = linspace(1,32);
[X,Y] = meshgrid(x,y);
Po = (X.*Y);
C = (Y.^2)*Kc;
I = X*Ki;
W = (X.^3)*Kw;
Pi = Po + C + I + W + Cl;
n = (Po./Pi).*100;
surf(X,Y,n);
xlabel('Speed/rad.sec');
ylabel('Torque/N.m');
zlabel('Efficiency %');
title('3D plot between torque, speed and efficiency');
    
```

4.4 Validation Model

To validate the real-time performance of the electric motor, a vehicle model and a controller are required so that the motor can be incorporated into it at various environmental conditions with a road profile (Fig. 6). The model was run at wide open throttle running for 30 s in which the throttle gets cut off after 20 s. Later, the road profile was changed using ECE Extra urban driving cycle, and the below results were obtained (Figs. 7, 8, 9).

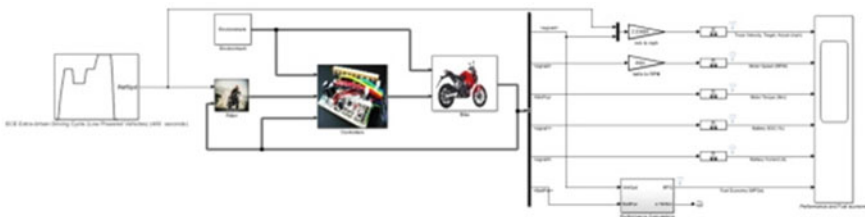


Fig. 6 Two-wheeler Vehicle model for validation

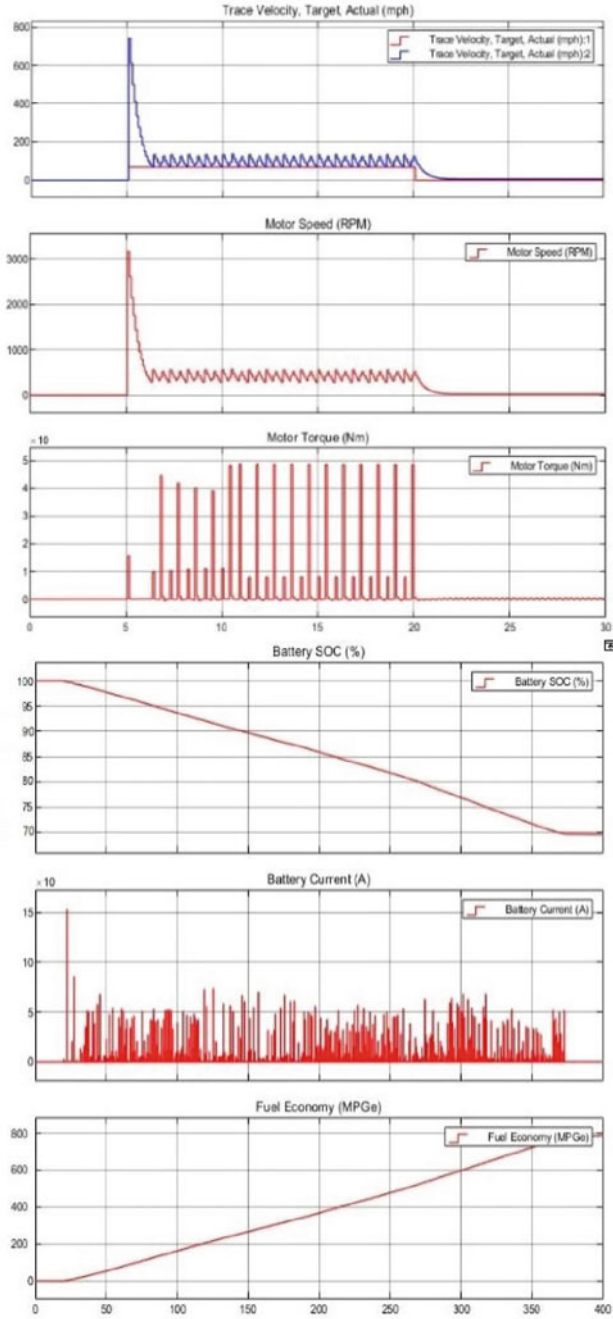


Fig. 7 WOT as road profile

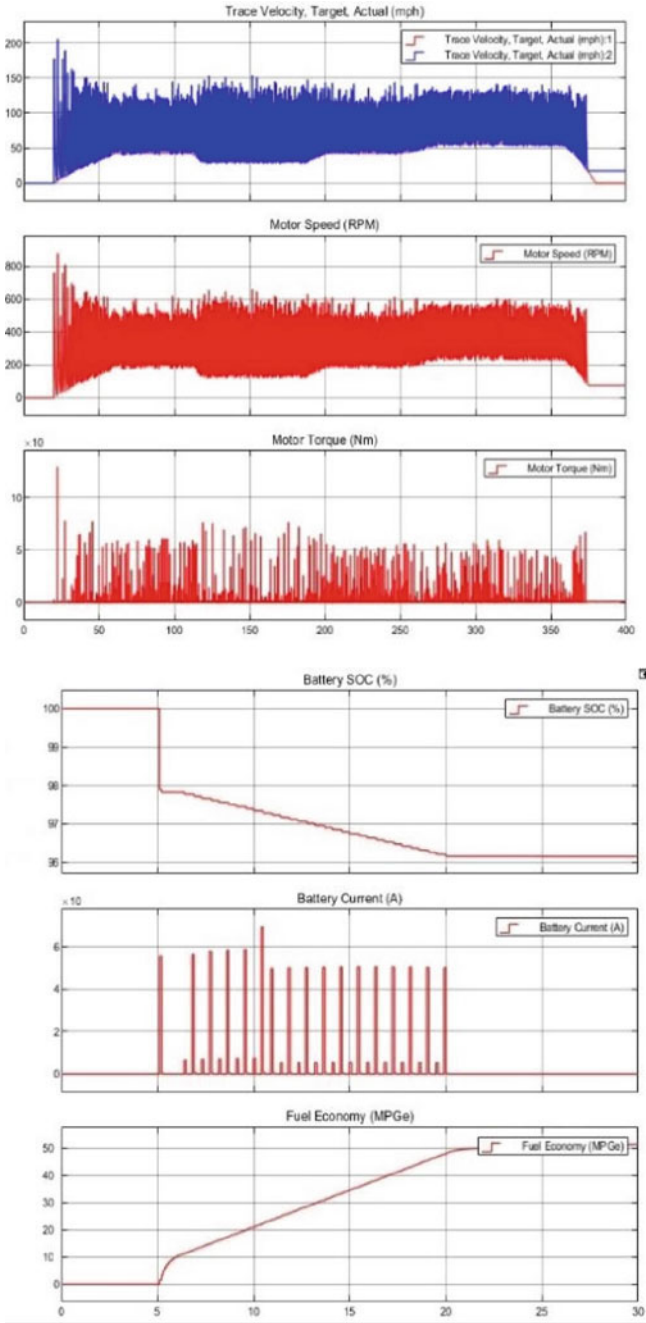
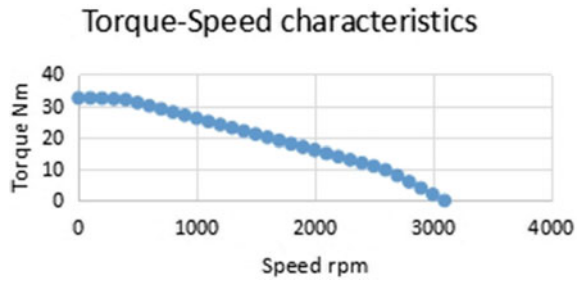


Fig. 8 ECE urban driving cycle as road profile

Fig. 9 Torque-speed result from simulation



5 Conclusion

The motor design gave the possibility to get the efficiency of the motor by detailing the losses encountered during a run. The mathematical model of motor provided the stator current, electromagnetic torque, electromotive force, and rotor speed. The validation model generated the torque speed characteristics and the torque obtained in this model is nearly equal to the torque generated by the motor in the real run at the same environmental and supply conditions.

In this research, we have studied the performance of a bldc hub motor used in electric two-wheeler and observed its performance at simulation level and experiment level. It was found that the result obtained in both the cases were all most similar and are as follows.

Obtained Torque = 32 Nm in simulation and 29 Nm in experimentation.

efficiency of the motor = 86% in simulation and 87% as specified by the manufacturer.

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