Development Of Three Wheeler Electric Vehicle With BLDC Motor

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Abstract

Environmental protection and energy issues have most active subject of interest and electric cars with Brushless DC motors are new energy efficient drives in industrial applications. In the present paper control system is designed to develop electric car brushless DC motor and numerical analysis is performed. The results illustrated that the brushless DC motor had good controllability and suitable for the application to the electric car.

Key Words: Environmental protection, Energy, Electric car, BLDC motor, MATLAB

1. Introduction

Latest advances in permanent magnet materials have resulted
Brushless DC motors are new energy efficient drives and very popular in industrial applications such as automotive, aerospace, industrial automation etc due to its high reliability and efficiency, low maintenance requirements and economy. BLDC motor is electronically commutated and finds numerous applications in motion control [1]. Overcome the challenge of implementing required control functions by new generation of microcontrollers and advanced electronics to make the BLDC motor more practical has [2-4]. Even though three-wheelers are lighter and cost of manufacturing is less, for poorly designed applications this platform is the less forgiving layout. In the present study aimed at ‘Modelling of three wheeler electric cars (tri-car) with BLDC motor to protect the environmental and save energy’[5].

2. Mathematical Model
2.1 Mathematical model of Three Wheeler Electric Vehicle
In the present study mathematical model of three wheeler electric car with BLDC motor is developed. Three wheeler electric vehicles, it is required to identify all forces which affects the dynamic behaviour of the vehicle and to determine the torque produced by forces on the vehicle when vehicle is stopped or in movement. There are several forces acting on the vehicle, but the major forces that affect the vehicle dynamics are static friction, rolling resistance, traction or braking force, aerodynamic drag force. A model of electric vehicle is used to determine the normal reaction on the front and rear wheel. The Parked vehicle dynamics are testing in the different road conditions i.e., level road and an inclined road.

Fig. 1: Vehicle dynamics on level road

Fig. 2: Parked vehicle on an inclined road
Planar static equilibrium equations are:

\[ \sum W = 0 \]
\[ \sum M = 0 \]
\[ W_f + 2W_r - mg = 0 \]
\[ -W_{d1} + 2W_{d2} = 0 \]
\[ \Rightarrow -W_f l_1 + l_2 (mg - W_f) = 0 \]
\[ \Rightarrow W_f = \frac{mg}{L} \]
\[ W_r = \frac{1}{2} (mg - W_f) \]
\[ \Rightarrow W_r = \frac{1}{2} (mg - \frac{l_mg}{L}) \]
\[ \Rightarrow W_r = \frac{mgl_h}{L} \]

(a) Parked vehicle on plane road

Planar static equilibrium equations are:

\[ 2F_{xz} - mg \sin \theta = 0 \]
\[ W_f + 2W_r - mg \cos \theta = 0 \]
\[ -W_{d1} + 2W_{d2} - 2F_{xz} h = 0 \]
\[ \Rightarrow W_f = \frac{1}{L} (mgL \cos \theta - mgh \sin \theta) \]
\[ \Rightarrow W_r = \frac{1}{2L} (mgL \cos \theta + mgh \sin \theta) \]
\[ \Rightarrow F_{xz} = \frac{1}{2} mg \sin \theta \]

(b) Parked vehicle on an inclined road

\( F_{xz} \) is the braking force applied on wheel. At maximum inclination angle, the braking force is proportional to the normal force. Therefore \( F_{xz} = f_r W_r \)

\[ W_f = \frac{1}{L} (mgL \cos \theta_M - mgh \sin \theta_M) \]
\[ W_r = \frac{1}{2L} (mgL \cos \theta_M + mgh \sin \theta_M) \]
\[ \Rightarrow \tan \theta_M = \frac{f_r}{L} (l_1 + h \tan \theta_M) \]
\[ \Rightarrow \tan \theta_M = \frac{f_1 l_1}{L - f_r h} \]

(c) Rear Wheel Braking

\[ \bar{W}_f = \frac{1}{L} (mgL \cos \theta_M - mgh \sin \theta_M) \]
\[ \bar{W}_r = \frac{1}{2L} (mgL \cos \theta_M + mgh \sin \theta_M) \]
\[ F_{xz} = mg \sin \theta_M \]
\[ \tan \theta_M = \frac{f_1 l_2}{L - f_r h} \]

(d) Front Wheel Braking
\[ f W_f + 2 f W_r - mg \sin \theta_M = 0 \]
\[ W_f + 2 W_r - mg \cos \theta_M = 0 \]
\[ -W_f l_1 + 2 W_f l_2 - (f W_f + 2 f W_r) h = 0 \]
\[ \tan \theta_M = f_r \]

(e) Three wheels braking

Where,

\( W_f \): Normal reaction of front wheel  \( W_r \): Normal reaction on rear wheel

\( L \): Wheel base \( l_1 \): Distance of centre of mass in the plane of front wheel

\( l_2 \): Distance of centre of mass in the plane of rear wheel \( \theta \): Angle of inclination

\( g \): Acceleration due to gravity in \( \text{m/s}^2 \) \( a \): Acceleration of the vehicle

\( R \): Radius of the wheel \( f_r \): Rolling friction of the wheel \( R_r \): Rolling resistance force

\( N \): Normal force on the wheel

NOTE: For achieving maximum acceleration the vehicle must be designed with rear wheel drive and all wheel brake.

2.2 MODELING OF BLDC MACHINE

Modelling of BLDC motor is similar to DC motor where two equivalent circuits i.e., electrical and mechanical equations. The main construction difference between BLDC and DC motor is that phase winding of the BLDC motor at the stator side and rotor contains permanent magnet, but in DC motor phase winding is at rotor side and stator contains permanent magnet.

\[ \begin{align*}
R_a & \quad \text{at} \quad a \\
R_b & \quad \text{at} \quad b \\
R_c & \quad \text{at} \quad c
\end{align*} \]

\[ \begin{align*}
L_a & \quad \text{at} \quad a \\
L_b & \quad \text{at} \quad b \\
L_c & \quad \text{at} \quad c
\end{align*} \]

\[ \begin{align*}
e_a & \quad \text{at} \quad a \\
e_b & \quad \text{at} \quad b \\
e_c & \quad \text{at} \quad c
\end{align*} \]

Fig. 4. Three phase Brushless DC motor equivalent circuit

For simplicity, the electrical model of one phase can be represented as stator winding, phase \( k \) \( (k = a, b \text{ or } c) \) is given by the equation

\[ V_{in}(t) = i_k R_x + L_x \frac{di_k(t)}{dt} + e_k(t) \rightarrow I \]
Where, \( V_{kn}(t) \) - Instantaneous of k-phase voltage, \( i_k(t) \) - Instantaneous of k-phase current,

\( e_k(t) \) - Instantaneous of k phase back- EMF voltage, \( R_k \) - k phase resistance,

\( L_k \) - k phase inductance

The mathematical model for the BLDC motor voltage equations are as follows by the assuming that the magnet has high sensitivity and rotor induced currents can be neglected and stator resistances of all the windings are equal. Hence there is no change in rotor reluctance with angle.

\[
\begin{bmatrix}
V_a \\
V_b \\
V_c \\
\end{bmatrix} = \begin{bmatrix}
R & 0 & 0 \\
0 & R & 0 \\
0 & 0 & R \\
\end{bmatrix} \begin{bmatrix}
i_a \\
i_b \\
i_c \\
\end{bmatrix} + \frac{d}{dt} \begin{bmatrix}
L_{ca} & L_{ba} & L_{cb} \\
L_{ca} & L_{ba} & L_{cb} \\
L_{ca} & L_{ba} & L_{cb} \\
\end{bmatrix} \begin{bmatrix}
i_a \\
i_b \\
i_c \\
\end{bmatrix} + \begin{bmatrix}
e_a \\
e_b \\
e_c \\
\end{bmatrix} \tag{1}
\]

The equation of motion is

\[
T_e(t) = J \frac{d\omega}{dt} + B\omega + T_l(t) \tag{2}
\]

Where, \( \omega \) - rotor angular velocity, \( B \) - viscous friction, \( J \) - moment of inertia, \( T_l \) - load torque

Total torque produced by motor is sum of the torque produced by individual phase

The following vehicle parameters are chosen:

- Mass of the vehicle is 300 kg, Aerodynamic coefficient is 0.3.
- vehicle front cross sectional area is 2.43 m\(^2\), Air density is 1.225 kg/m\(^3\)
- \( L = 2.6 \) m, \( l_1 = 1.6 \) m, \( h = 0.8 \) m, \( J = 0.30 \) kg-m\(^2\), \( R = 0.25 \) m, \( f = 0.02 \)

The Brushless DC motor drive during speed and torque regulation is developed in MATLAB as shown in the Fig. 5

![Brushless DC motor drive diagram](image)

Fig. 5: Brushless DC Motor Drive during Speed and Torque regulation

3. Simulation Results

Design and simulation of BLDC motor drive was done using MATLAB (SIMULINK) and results of simulation parameters are given in TABLE 1.
TABLE 1: Simulation parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC Voltage</td>
<td>220V</td>
</tr>
<tr>
<td>$L_s$</td>
<td>8.5e-3 H</td>
</tr>
<tr>
<td>Fundamental frequency</td>
<td>60 Hz</td>
</tr>
<tr>
<td>$J$</td>
<td>0.089 kg·m²</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>10 kHz</td>
</tr>
<tr>
<td>$B$</td>
<td>0.005 N.m.s.rad⁻¹</td>
</tr>
<tr>
<td>$R_s$</td>
<td>0.2 Ω</td>
</tr>
<tr>
<td>$K_b$</td>
<td>0.5128 V/rad/sec</td>
</tr>
</tbody>
</table>

Fig. 6: Electromagnetic torque Vs Time

The above graph shows the variation of electromagnetic torque in N-m with respect to time. The starting value of stator electromagnetic torque is very high due to starting of the motor. The electromagnetic torque varies continuously till $t = 1.5$ secs and then becomes constant.

Three wheel drive dynamics simulation model is developed in MATLAB as shown below and workspace variables are defined.
The result of vehicle velocity, horizontal tire forces, vertical tire forces and wheel RPMs with respect to time is shown below. In below shown graphs the Tire F denotes the front wheel, Tire RL denotes the rear left wheel and Tire RR denotes the rear right wheel.

From $t = 0$ to 4.5 sec the two wheels having different Horizontal tire forces, but at 2 secs and beyond 4.5secs both have almost equal Horizontal tire forces acting on them.
From $t = 0$ to 5 secs the both the wheels having different Vertical tire forces. The front tire is having more Vertical force acting on it at $t = 0$ secs and after $t=2.2$ secs, but beyond 4.5 secs different constant vertical tire forces acting on them.

The variation of vehicle velocity with respect to time is shown in above graph. At $t = 0$ sec the vehicle velocity is maximum and after it decreases linearly with respect to time and then increases linearly beyond 4.5 secs.

At $t = 0$ sec all the wheels are having zero RPM and then increase gradually with front wheel having the higher RPM and both rear wheels running with equal RPM beyond 4.5 secs.
4. Conclusion

The present work three-wheeled car dynamic performance and stability are investigated. As the science and technology is developing day by day and the ideas of energy conservation are being more and more popular in the society, electric car will take a greater part in people's daily life. This paper analyse the principle of brushless DC motor used in the electric car. The brushless DC motor was modelled in MATLAB Simulink. Analysis is done, which would help the further popularization for application of the brushless DC motor for improving the vehicle performance.

References


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