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# DESIGN AND CONTROL OF LIGHT WEIGHT ELECTRIC VEHICLE

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***Abstract*** — *The development of internal combustion engine automobiles is one of the greatest achievements of modern technology. However, the highly developed automotive industry and the increasingly large number of automobiles in use around the world are causing serious problems for the environment and hydrocarbon resources. The deteriorating air quality, global warming issues, and depleting petroleum resources are becoming serious threats to modern life. Progressively more rigorous emissions and fuel efficiency standards are stimulating the aggressive development of safer, cleaner, and more efficient vehicles. It is now well recognized that electric, hybrid electric, and fuel-cell powered drive train technologies are the most promising vehicle solutions for the foreseeable future. Now today traffic problem is more. So for reducing the traffic problem electric bicycle is useful now-a-days. There are different types of motor used like Induction Motor (IM), Permanent Magnet Brushless DC Motor (PMBLDC), Switched Reluctance Motor (SRM), Brushed DC motor for electric vehicle. According to high efficiency, construction, high torque to weight ratio PMBLDC motor widely used. There are different types of battery used for electric vehicle. We can also make modeling of electric bicycle with various parameters. In this paper modeling and simulation for speed control of PMBLDC motor with the help of PWM technique is explained. And get various simulation results with different duty ratio.*

***Keywords***- *Electric bicycle, PMBLDC motor, PWM, Lithium ion battery, Inverter, Sensor control, MATLAB, Modeling and simulation.*

## I. INTRODUCTION

The first demonstrations of electric vehicles are made in 1830s which is invented by Thomas Davenport, Robert Anderson. At that time no rechargeable batteries are used. By the end of $19^{th}$ century commercial electric vehicle are available. The principle behind the design of EVs are environmental issues are understood [1]. Electric motorcycles (e-bikes) gaining popularity in India due to Steady rise in petroleum fuels & Environmental issues. So it seems that there is no turning back at lower prices, such scenarios are making one to think about electric powered vehicles. To start with such invention an electric bicycle can be a basic to understand the behavior of electric propulsion. For Short travelling distance to reach at the work & if traffic is crazy around here so using car is suicidal. Also, there are not enough parking spaces and the once available are quite expensive. With the e-bike you can avoid the traffic jams, the never ending parking searching. Table 1 gives the comparison between conventional fuel bike and electric vehicle. There are three main components of electric vehicle battery, electric motor, and power converter. In this paper we have used PMBLDC motor for propulsion and control its speed by PWM control with different duty ratio. In following section we can show modeling of electric bicycle, battery selection and different types of motor selection for electric bicycle.

***Table 1. Comparison between conventional fuel bike and electric vehicle***

| Sr. No | Conventional fuel bike | Electric vehicle |
|---|---|---|
| 1 | Operate on petroleum fuel | Operate on DC battery |
| 2 | High speed (40-60Kmph) | Less speed (20 40Kmph) |
| 3 | High cost of purchase & maintenance | Low cost of purchase & maintenance |
| 4 | Licenses required | Licenses not required |
| 5 | Taxes need to be paid | No taxes need to be paid |
| 6 | Pollutes environment | Friendly environment |
| 7 | Efficiency is low | Efficiency is high |
| 8 | Fuel capacity (300- 600Kms) | Battery capacity (50-70Kms) |

 

## II. MODELING OF ELECTRIC BICYCLE

The first step in vehicle performance modeling is to produce an equation for the tractive effort. This is the force propelling the vehicle forward, transmitted to the ground. There are different types of forces occurred on bicycle like [1]:

1). Rolling Resistance Force (F roll)
2). Hill Climbing Force (Slope) (F slope)
3). Acceleration Force (F accle)
4). Aerodynamic Drag (Fad) or Wind Force (F wind)

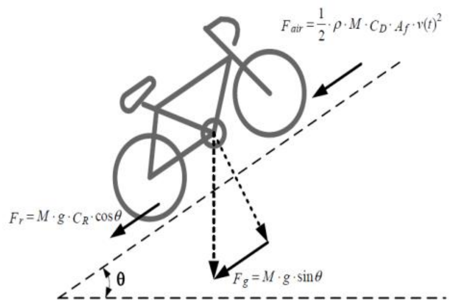


***Figure 1. Forces on electric bicycle [3]***

Equation of the total tractive effort of electric bicycle is:
**Fte = Frr + Fad + M*g *sin ψ + M*a + [1/r^2]*a**
**Where** Fte = Tractive effort = [Tm/r]
Frr = Rolling Friction
Fad = Air drag
M*g*sin ψ = Weight
M*a = Acceleration
a = dv / dt
Wm = [V/r]
r = Radius
V = Velocity in m / sec

### 2.1. Rolling Resistance Force ( F roll ):

It is primarily due to the friction of the vehicle tier on road. It is depend on vehicle speed. It is proportional to vehicle weight. The typical value of μ **= 0.0015 to 0.015.** It is given by [1],

**Frr = μ × M × g x cos (θ)**
Where, μ = Co-efficient of rolling resistance.
M = Total mass of the vehicle.
g = acceleration due to gravity = 9.81 m/s^2

### 2.2. Hill Climbing Force (F slope) :

The force needed to drive the vehicle up – a slope is the most important to find. It is also known as weight. It is given by,

**F Slope = M × g x sin (θ)**

### 2.3. Acceleration Force (F accel ) :

If the velocity of the vehicle is change then clearly a force will need to apply in addition to the force. It can provide linear acceleration of the vehicle. It is given by Newton's second law,

**Faccel = m × a**
**Where,** a = acceleration in m/s^2

### 2.4. Aerodynamic Drag:

Force is due to the friction of the vehicle body moving through the air. It is a function of frontal area, shape, other factor like mirrors, ducts, spoilers & air passages.
It is given by,

**Fad = (ρ × Cd × A × V^2) / 2**
**Where,** ρ = Air density = 1.25kg/m^3
A = Frontal area m^2
V = Velocity in m/s
Cd= Constant (winding co-efficient)

 

**2.5. Mathematical Calculation:**

In this paper we can calculate the total force occurred on bicycle by using above all equations. Here first we can find the peak power of the motor at starting point with velocity of (0 km/h – 30 km/h) for 20 sec and then second we can also find the motor power during the continuous period for 20 second by using the different parameters which are shown in Table 2 and Table 3

***Table 2. Mass calculation of electric bicycle [3]***

| Components | Mass in kg |
|---|---|
| Bicycle assembly | 10 |
| Motor | 3 |
| Power Control | 1 |
| Battery | 6 |
| Cyclist | 75 |
| **Total Weight** | **95** |

***Table 3. Parameters of electric bicycle components [3]***

| | |
|---|---|
| Co-efficient of rolling friction µ | 0.0015 – 0.015 |
| Co-efficient of drag cd | 0.3 – 0.7 |
| Gravity | 9.81 kg/m2 |
| Frontal area | 0.50 m2 |

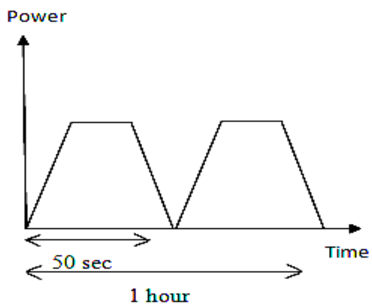


***Figure 2. Power Vs Time Curve***

This is the total calculation for 50 sec and same is done for another 50 sec period. So the total requirement of continuous power for the motor is 121.313 for 30 km/h. So following Table 4 shows the results obtained from the above equations for modeling of electric bicycle.

***Table 4. Results for modeling of electric bicycle***

| | |
|---|---|
| Speed Requirements N | 397 RPM |
| Peak Power at starting condition P1 | 450.83 watts |
| Torque at starting condition T1 | 10.82 Nm |
| Power at continuous condition P2 | 121.31 watts |
| Torque at continuous condition T2 | 2.91 Nm |

## III. BATTERY SELECTION

The power source for the electric bicycle will be battery. But now different types of battery used for electric vehicle. Following batteries are used for electric vehicle [4].

(A). Lead-acid
(B). Nickel-Cadmium (Ni-Cd)
(C). Nickel-Metal Hydride (Ni-MH)
(D). Lithium-ion (Li-ion)

 

In early days the most common battery used for electric vehicle is lead acid battery which is rechargeable battery and very cheapest battery. But today lithium - ion batteries are widely used in electric vehicle due to following advantages [4]:

- Higher cell voltage
- The specific energy, for example, is about three times that of lead acid batteries.
- Higher specific power (kW/kg).
- Higher specific energy (Wh /kg).
- Low self-discharge.
- Longer life cycle.

**3.1. Comparison between lead acid and lithium ion battery:**

Here we compare following parameters of battery for 20 Km/h, 30 Km/h & 40 Km/h for electric bicycle. Based on the parameter of lead acid and lithium ion battery given in Table 2 we can calculate peak power and continuous power requirement for the electric bicycle which in shown in Table 3.

- Total weight of bicycle including cyclist
- Total weight of bicycle without cyclist
- Battery weight
- According to motor peak power
- According to motor power continuous power

***Table 4. Parameter of lead acid & lithium ion battery [5]***

| Parameter | Lead Acid Battery | Lithium Ion Battery |
|---|---|---|
| Nominal Voltage | 2.0 V/cell | 3.7 V/cell |
| Combination | 6 Cells | 4 Cells |
| Voltage | 12 V | 14.8 v |
| Capacity (Assume) | 100Ah | 100 Ah |
| Wh Capacity | 1200 Wh | 1480 Wh |
| Weight | 34.3 kg | 8.2 kg |
| Wh / kg | 34.98 Wh / kg | 180.48 Wh/kg |

In this paper we make the comparison between lead acid and lithium ion battery from the above parameter which is shown in Table 5.

***Table 5. Battery Comparison***

| Parameters | Lead Acid Battery | | | Lithium Ion Battery | | |
|---|---|---|---|---|---|---|
| | 20 Km/h | 30 Km/h | 40 Km/h | 20 Km/h | 30 Km/h | 40 Km/h |
| Total weight of bicycle including cyclist | 91.138676 Kg | 94.33892 Kg | 99.89650 Kg | 89.40952 Kg | 90.01039 Kg | 91.03009 Kg |
| Total weight of bicycle without cyclist | 16.138762 Kg | 19.33892 Kg | 24.89650 Kg | 14.40952 Kg | 15.01038 Kg | 16.030090 Kg |
| Battery weight | 2.13876 Kg | 5.33892 Kg | 10.89650 Kg | 0.40952 Kg | 1.01038 Kg | 2.03009 Kg |
| Peak power of Motor at starting | 187.3961 W | 448.83699 W | 874.53450 W | 184.3499 6 W | 432.3919 2 W | 815.93796 W |
| Motor power after starting point | 46.68260 W | 121.27128 W | 257.88957 W | 46.30545 W | 119.8558 5 W | 254.02382 W |

 

So, from this comparison given in Table 5 we can see that, if we want lighter weight battery and high specific energy then we use **lithium ion battery** .But if we consider the cost of battery then we use **lead acid battery** which is the cheapest battery as compared to lithium ion battery. It is more effective to use lithium ion battery for 40 Km/h according to weight of battery. Here lithium ion battery is five time lighter in weight.

## VI. MOTOR SELECTION

There are various types of motor used for electric vehicle. The main four motor is used for electric vehicle are as follows:

1). Brushed DC motor
2). Induction Motor
3). Switched Reluctance Motor
4). Permanent Magnet Brushless DC Motor

The HUB motor is widely used in light weight electric vehicle. It is the compact electric motors built into each wheel instead of engines. This type of motor placed inside the wheel and it is directly connected to the rotating wheel – (External rotor motor). On older electric bike frames the motor would hang off the side of the bike and drive the rear wheel via second chain. The bike becomes unbalanced with extra weight hanging on one side, and the motor is exposed and easily damaged if the bike were tipped over. So for light weight of vehicle HUB motor is effective to use in vehicle. So the Hub motor bicycles are much more reliable. It can generate high torque at low rpm [6] [7] [8].


***Figure 3. HUB Motor***

**Features of motor for electric bicycle:**

1). It should have short term overload capability for requirements cursing.
2). Higher power density & batter efficiency.
3). Reliability is higher.
4). Reduced the vehicle weight for extending the driving range.
5). It has good controllability, good dynamic performance.

***Table 6. Comparisons between different types of motor***

| Motor Type | Advantages | Disadvantages |
|---|---|---|
| **Induction Motor** | **Simple construction ,High reliability, Ruggedness, Low maintenance, Low cost, Ability to operate in hostile environment.** | **Controller for IM is higher cost than the DC motor, Breakdown torque is present which limit its extended constant power operation, Efficiency of I.M is inherently lower than the PM motor & SRM.** |
| **Switched Reluctance Motor** | **Simple & rugged construction, Fault tolerant operation, Control is simple, It can operate with an extremely long distance power range, High starting torque.** | **Suffer from torque ripple. Acoustic noise is occurred** |
| **Brushed DC Motor** | **Ability to achieve high torque at low speed, Being suitable to propel the vehicle and easy to be controlled they have been used in Evs.** | **Bulky construction, Low efficiency, Low reliability, Higher need of maintenance, Brushed DC motor more heavy & expensive.** |
| **Brushless DC Motor** | **High power to volume ratio, High efficiency & power density, Longer life, High starting torque. High no load speed. Small energy loss.** | **Magnet is expensive, Mechanical strength of the magnet is difficult, Suffer from field weakening capability, Higher initial cost, Poor high speed capability.** |

## V. MATLAB SIMULATION & RESULTS

### 5.1. Mathematical modeling of PMBLDC motor:

The basic block diagram for simulation of BLDC motor drive is shown in below:

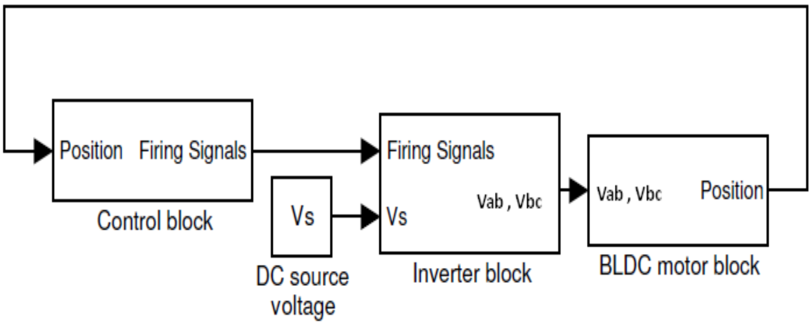


**Figure 6. Block diagram for simulation of BLDC motor [12]**

Figure 6 shows that the BLDC motor are powered by a conventional three phase inverter which is controlled based on rotor position information. So rotor positions are required for the electronic commutation. Generally hall sensors are used to detect position of rotor. Depending upon the hall sensor output pattern, the appropriate windings are energized through inverter switches. At any instant only two windings are energized so BLDC operate in 120 degree mode.

**Three phase star connected BLDC motor can be described by the following equations:**

V ab = R (ia-ib) +L d/dt (ia-ib) + ea-eb (1)

V bc = R (ib-ic) +L d/dt (ib-ic) + eb-ec (2)

V ca = R (ic-ia) + L d/dt (ic-ia) + ec-ea (3)

Te = B*wm + J d / dt (wm) +TL (4)

**Where** V = Phase to phase voltage
I = Phase current
e = Phase back emfs
R = Resistance (ohms)
L = Inductance (mH)
Te = Electrical torque
TL= Load torque
J= Rotor inertia (kg/m^2)
Wm= Rotor speed
B= Friction co-efficient

**The back emf & electrical torque can be express as:**

Ea = Ke x wm x F (θe)
Eb = Ke x wm x F (θe – 2Π/3)
Ec = Ke x wm x (θe - 4Π/3)
Te = Kt [F (θ)*ia + F (θe – 2Π/3)*ib + F (θe - 4Π/3)*ic

**Where** Ke = Back emf constant
Kt = Torque constant
F (θ) function gives Trapezoidal back emf waveforms.

**One period of this function can be written as**

$$F(\theta_e) = \begin{cases} 1, & 0 \le \theta_e < \frac{2\pi}{3} \\ 1 - \frac{6}{\pi}\left(\theta_e - \frac{2\pi}{3}\right) & \frac{2\pi}{3} \le \theta_e < \pi \\ -1 & \pi \le \theta_e < \frac{5\pi}{3} \\ -1 + \frac{6}{\pi}\left(\theta_e - \frac{5\pi}{3}\right) & \frac{5\pi}{3} \le \theta_e < 2\pi \end{cases} \quad (5)$$

Now, equations (1) - (4) written in state space form. This equation should be modified to allow the state space representation. Since each voltage equation is linear combination of the other two voltage equations only two equations are needed.

 

**So we get current relation**

Ia + Ib + Ic = 0 (6)

**Then voltage equations become:**

Vab = R (ia-ib) +L d/dt (ia-ib) + ea-eb
Vbc = R (ia+2ib) + L d/dt (ia+2ib) + eb-ec (7)

**And complete model is then,**

$$\begin{pmatrix} I'a \\ I'b \\ W'm \\ \theta'm \end{pmatrix} = \begin{pmatrix} -\frac{R}{L} & 0 & 0 & 0 \\ 0 & -\frac{R}{L} & 0 & 0 \\ 0 & 0 & -\frac{Kf}{J} & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} Ia \\ Ib \\ Wm \\ \theta m \end{pmatrix} + \begin{pmatrix} \frac{2}{3L} & \frac{1}{3L} & 0 \\ -\frac{1}{3L} & \frac{1}{3L} & 0 \\ 0 & 0 & \frac{1}{J} \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} Vab - Eab \\ Vbc - Ebc \\ Te - Tl \end{pmatrix}$$

$$\begin{pmatrix} Ia \\ Ib \\ Ic \\ Wm \\ \theta m \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ -1 & -1 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} Ia \\ Ib \\ Wm \\ \theta m \end{pmatrix} \quad (8)$$

According to above equations simplified equations are shown in below which is used for two built the simulink model of BLDC motor [12].

**For current generation:**

d/dt (ia) = (-R/L)*ia + (2/3L)*Vab + (1/3L)*Vbc – (2/3L)*(eab) – (1/3L)*ebc
ia = (1/3L) ⌡ [2Vab + Vbc – 2ea + eb + ec – 3R*ia] (9)

d/dt (ib) = (-R/L)*ib - (1/3L)*Vab + (1/3L)*Vbc + (1/3L)*(eab) – (1/3L)*ebc
ib = (1/3L) ⌡ [-Vab + Vbc + ea - 2eb + ec – 3R*ib] (10)

ic = -ia – ib. (11)

**For speed and torque generation:**

d /dt (Wm) = 1/J [Te – TL – B wm]
Wm = ⌡ 1/J (Te – TL – B wm) (12)
We = P/2*wm
θe = ⌡we (13)

So from above equations modeling of BLDC motor is done in MATLAB simulation. In this paper we can generate the hall sensor signal by using the switching sequence according to hall pattern which is shown in Table 6.

**Table 7. Switching Sequence According To Hall Pattern**

| Mode | Hall Sensor output | | | Inverter Switch | | | | | | Phase Voltage | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | H1 | H2 | H3 | S1 | S2 | S3 | S4 | S5 | S6 | Va | Vb | Vc |
| 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | $V_{dc}/2$ | $-V_{dc}/2$ | 0 |
| 2 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | $V_{dc}/2$ | 0 | $-V_{dc}/2$ |
| 3 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | $V_{dc}/2$ | $-V_{dc}/2$ |
| 4 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | $- V_{dc}/2$ | $V_{dc}/2$ | 0 |
| 5 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | $- V_{dc}/2$ | 0 | $V_{dc}/2$ |
| 6 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | $-V_{dc}/2$ | $V_{dc}/2$ |

**PMBLDC motor parameter:**

Battery voltage= 36V,
Phase resistance = 0.5Ω,
Phase inductance = 1.65mH,
Speed = 3500 RPM
Pole pair = 4
Rated torque = 0.32 Nm
Inertia = 17.3*e-4 Kg*m^2
Rated current =10 A

### 5.2. MATLAB simulink model of PMBLDC motor:

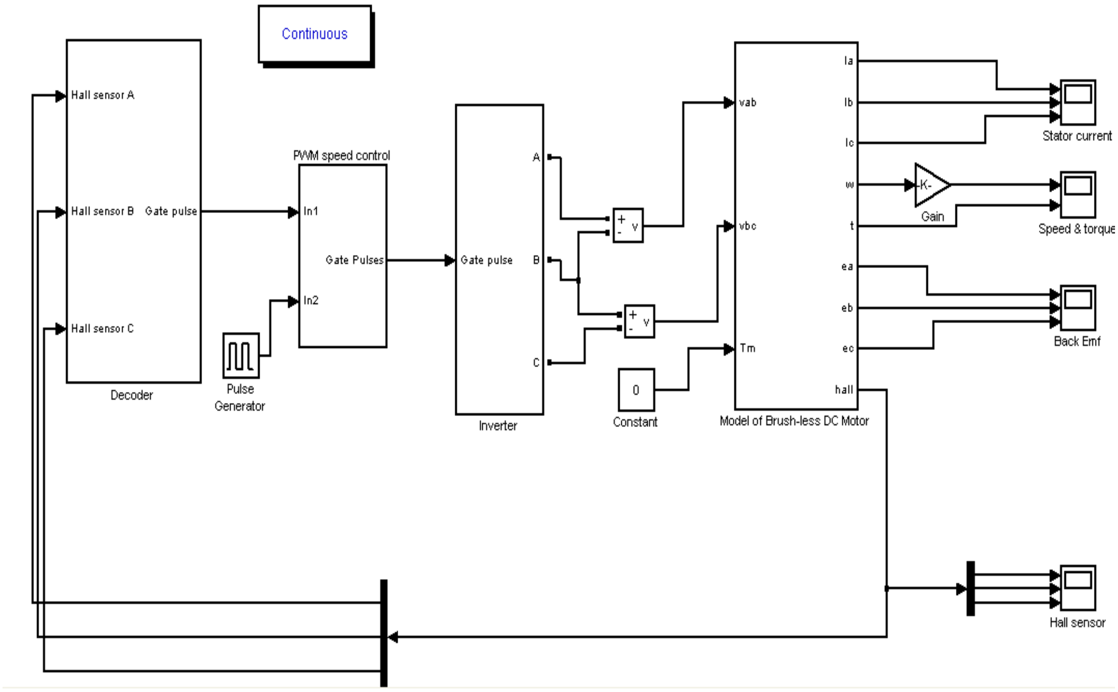


***Figure 7. Speed Control of PMBLDC Open Loop with PWM***

In Figure 7 four main blocks are used decoder, PWM speed controller, inverter, model of PMBLDC motor. Here hall sensor are generated in M-file of the MATLAB software with the help of hall sensor switching sequence shown in Table 6.Then this signal is given to the inverter and six gate pulse S1-S6 are generated. Output of the inverter phase voltage is given to the input of the PMBLDC motor. Model of PMBLDC motor is made using the above equation and back emf is generated in trapezoidal nature in 120 degree mode and speed is controlled by varying with different duty ratio of PWM generator.

In sensored BLDC drive with PWM, switching signals of upper switches are chopped with 10 KHz frequency. Torque repulsion decreases and speed can be varied in open loop. So in this system, as ON time period is increased speed of the motor increased.

### 5.3. Simulation results:

#### 5.3.1. When load torque is zero:

Here, Figure 8 and Figure 9 Shows the stator current and back emf waveforms & Figure 10 and figure 11 shows the speed and torque waveform under a no load condition with 50% pulse width and with 70% duty ratio.

**Stator current & back emf waveform:**

**With duty ratio 50%** **With duty ratio 70%**

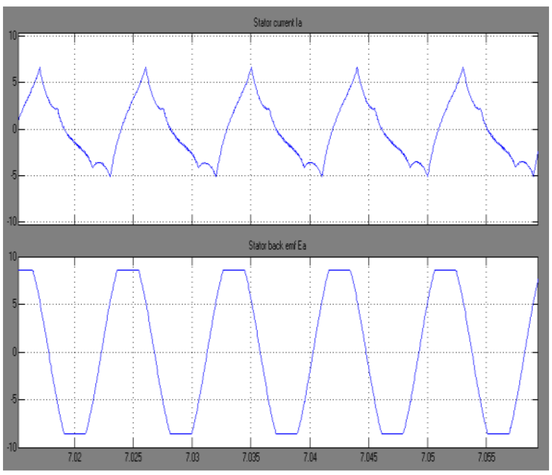

***Figure 8. Stator current & back emfwaveform***

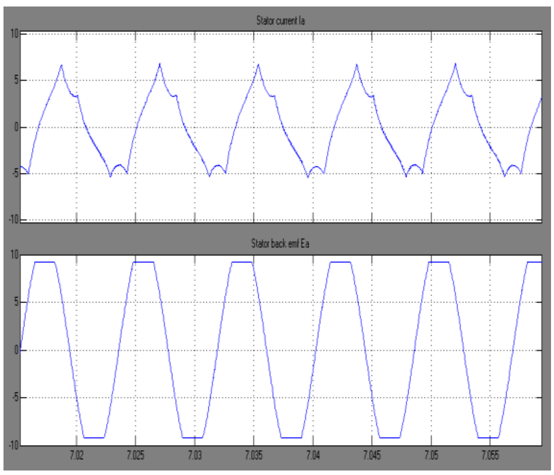

***Figure 9. Stator current & back emf waveform***

 

**Speed & Torque Waveform:**

**With duty ratio 50%**

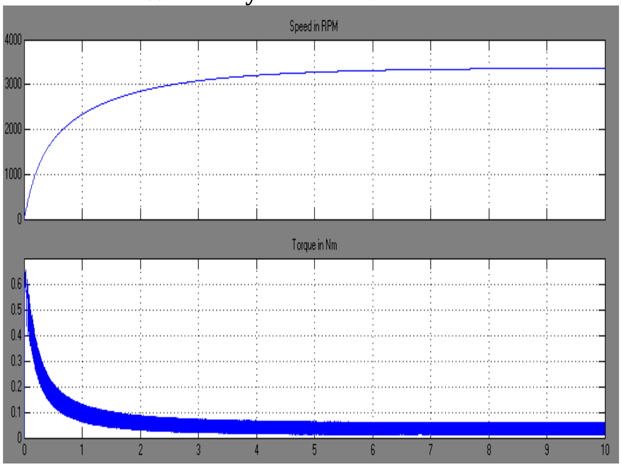


*Figure 10. Speed & torque waveform*

**With duty ratio 70%**

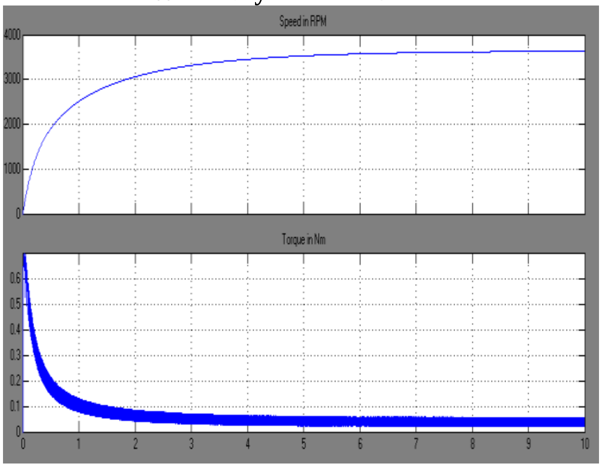


*Figure 11. Speed & torque waveform*

**5.3.2. When load torque is 0.32 :**

Here, Figure 12 and Figure 13 Shows the stator current and back emf waveforms & Figure 14 and figure 15 shows the speed and torque waveform under a no load condition with 50% pulse width and with 70% duty ratio.

**Stator current & back emf waveform:**

**With duty ratio 50%**

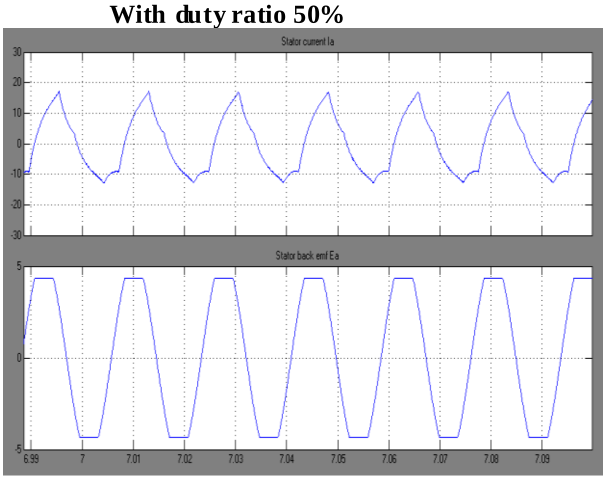


*Figure 12. Stator current & back emfwaveform*

**With duty ratio 70%**

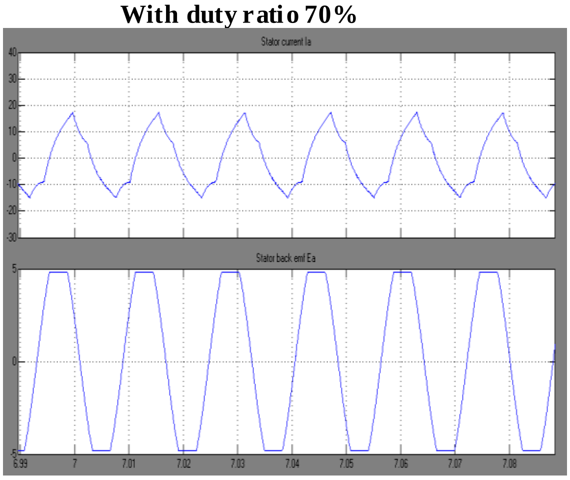


*Figure 13. Stator current & back emf waveform*

**Speed & Torque Waveform:**

**With duty ratio 50%**

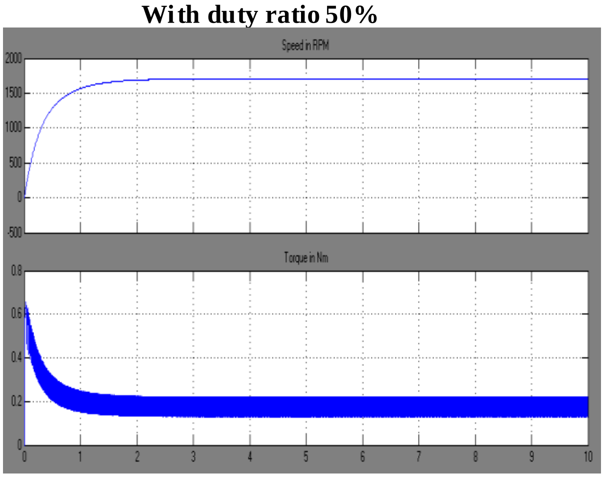


*Figure 14. Speed & torque waveform*

**With duty ratio 70%**

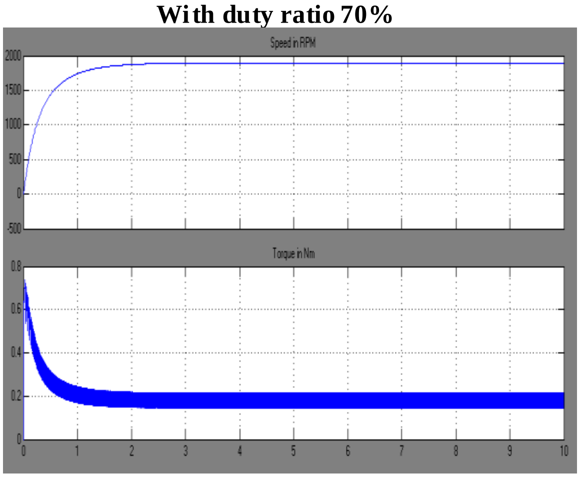


*Figure 15. Speed & torque waveform*

 

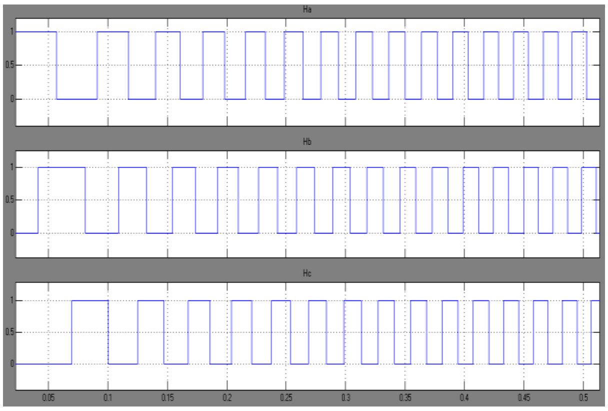

**Figure 16. Hall Sensor Waveform**

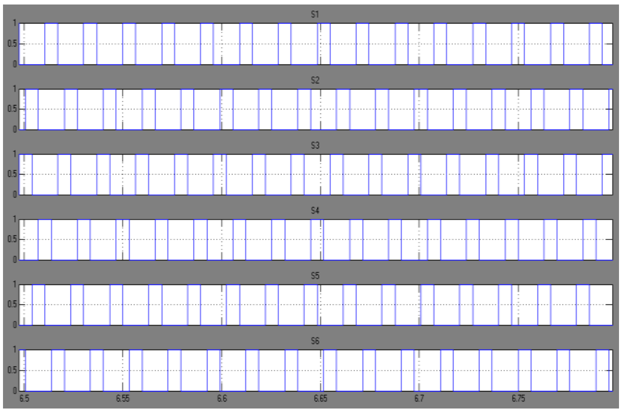

**Figure 17. Inverter Switch S1-S6 Waveform**

So from above simulation results we can say that, here we study when duty ratio 50% to 70% with load torque zero speed varies between 3363 RPM to 3631 RPM. It means increasing the duty ratio then speed of the motor increased and a torque pulsation is reduced. When duty ratio 50% to 70% with load torque 0.32 speeds increased from 1706 RPM to 1894 RPM. And its speed is lower as compared to no load torque given to the motor. Here we got different simulation results with different duty ratio. Figure 16 and Figure 17 shows the waveform of hall sensors and switching of the inverter circuit according to switching pattern of hall sensor.

## VI. Conclusion

For environmental safety & protection we should use electric vehicle instead of internal combustion engine vehicle. Use of electric vehicle reduces the noise pollution. Here we study modeling of electric bicycle. Different electric motors are used for EVs among them PMBLDC motor is best candidate now-a-days for EVs because of high efficiency, long operating life, and high dynamic response, better speed V/S torque characteristics, high speed ranges, noiseless operation, and rugged construction..We also study different types of battery used for electric vehicle. Make comparison between lead acid battery & lithium ion battery and justify which battery is mostly used for EVs. The results illustrated in this paper can help in systematic study of electric propulsion and design an electric bicycle to the ratings of one's requirement. Here electric propulsion system using BLDC motor with sensored speed control along with smooth running operation is shown & in future sensor less operation can be adopted to overcome limitations & expenses of sensors. The system performance can be improved if renewable energy sources like solar power can be employed. Also efficient modern world energy storage devices like Ultra capacitors and even fuel cell technology can be incorporated as a source of power.

## REFERENCES

[1]. James Larminie (Oxford Brookes University, Oxford, UK), John Lowry (Acenti Design Ltd, UK), John Wiley & Sons. Ltd "Electric Vehicle Technology Explained").
[2]. http://www.ecoideaz.com/showcase/electric-bikes-on-indian-roads
[3]. Srivatsa Raghunath "Hardware Design Considerations for an Electric Bicycle Using a BLDC Motor" Application Report SLVA642–June 2014.
[4].Irene Berry, Mike Khusid, Manolis Kasseris, and Arthur Mak; MIT Electric Vehicle Team "What's the Deal with Hybrid and Electric Cars ? " January 20 , web.mit.edu / evt /iap2009.
[5]. Asian Development bank, "Philippines: Mitigation of Climate Change through Increased Energy Efficiency and the Use of Clean Energy, Lead Acid: A Growing Environmental Problem".
[6]. Stephen J. Mraz Senior Editor "Hub Motors for All-Electric Vehicles Still Have Some Technological Challenges to Overcome' Aug 10, 2010).
[7]. http://www.explainthatstuff.com/hubmotors.html
[8]. http://www.nycewheels.com/hub-motor-bicycle.html
[9]. Mounir Zeraoulia, Mohamed El Hachemi Benbouzid, and Demba Diallo, "Electric Motor Drive Selection Issues for HEV Propulsion Systems: A Comparative Study", *IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY,* VOL 55, NO. 6, November 2006, pp. 1756-1764.
[10]. Padmaraja Yedamale, "Brushless DC (BLDC) Motor Fundamentals" AN 885, Microchip Technology Inc.
[11]. Priya darshini J Patil, Jyoti P Koujalagi, "Modeling and Simulation of BLDC Motor based Propulsion System For Electric Bicycle" M. tech (Power Electronics), Professor, Dept. of Electrical & Electronics Eng. Dr. Ambedkar Institute of Technology, Bangalore, India International Journal of Electrical, Electronics and Computer Systems (IJEECS), 2014.
[12]. Master Thesis work by Stefán Baldursson, "BLDC Motor Modeling and Control – Matlab ®/Simulink® Implementation.

 