Assessment Of BLDC Drive For E-Bike Application

Paul Sathiyan, Benin Pratap, Daniel, Arun

Abstract*: *This paper describes about the need and the various architecture of Electric Bike (E-bike). Among the various electric propulsion sources available, the performance study of Brushless DC (BLDC) motor for an electrically assisted bicycle (E-Bike) is carried out under certain operating conditions. In order to determine the operating speed and to achieve a suitable gear ratio, the motor is operated at different duty ratios whereby the operating voltage and speed of rotation of the motor is varied. The motor is loaded during the various test speeds considered. Based on the performance of the motor and the norms set by Central Motor Vehicle Rules (CMVR) of India, the torque delivered by the motor is computed through experimentation. The characteristics graphs have been plotted against different parameters. Depending on the torque values at the recommended power, the motor operating speed, voltage and currents were identified. Suitable gear ratios have been identified to match the performance of the motor with the e-bike performance requisite leading to better performance of the E-Bike propulsion system.

Keywords: Electric Bike, BLDC Motor, Buck Converter, TMS320F2812.

I. INTRODUCTION

Transport infrastructure and highly connected road networks pay way for better transportation and economic growth of a country. Due to this, there is a tremendous growth in the production of road transport vehicles out of which the market is significantly dominated by two wheelers. The main pollutants emitted from the automobiles are hydrocarbons, lead/benzene, carbon monoxide, sulphur dioxide, nitrogen dioxide and particulate matter. Usage of two wheelers have contributed to two third of the pollution in major cities in India. Two wheelers give out nearly 30% particulate matter load and 10% more than from the cars [1]. Two wheelers with two stroke engine, records an additional of 75% to 80% pollution level. According to the sources, two wheelers in Bengaluru, contribute to 65 % and 50 % hydrocarbons and carbon monoxide [2]. According to [3], two wheelers contributed to 260, 190 and 330 grams of CO2 equivalent per passenger kilometer in urban, rural and highway driving. The emissions levels are found to be higher at low speeds. Due to the higher traffic density, the average speed of travel in urban areas have come down between 18 and 20 kmphr [4]. To summarize, the usage of two wheelers in urban regions is found more operating at lower speeds emitting higher level of pollution.

At this juncture, E-bike could be an alternative solution for urban transportation. The rest of the article discusses on the various available models of E-bike and its characteristics, propulsion mechanism, performance evaluation and testing of BLDC motor for E-Bike application.

Revised Manuscript Received on September 2, 2019.

S. Paul Sathiyan*, Department of Electrical and Electronics Engineering, Karunya Institute of Technology and Sciences, Coimbatore, India. Email: sathiyanme@yahoo.co.in

C. Benin Pratap, Department of Electrical and Electronics Engineering, Karunya Institute of Technology and Sciences, Coimbatore

Daniel, Department of Electrical and Electronics Engineering, Karunya Institute of Technology and Sciences, Coimbatore

Arun, Department of Electrical and Electronics Engineering, Karunya Institute of Technology and Sciences, Coimbatore

II. LITERATURE AND MARKET SURVEY

A. E-Bike Architecture

Based on the motor vehicle regulation of a country, the e-bike configuration is classified broadly into two major categories as given below.

- Pure Electric Propulsion (Fig. 1)
- Pedal + Electric (Pedaelec Model) Propulsion (Fig. 2)

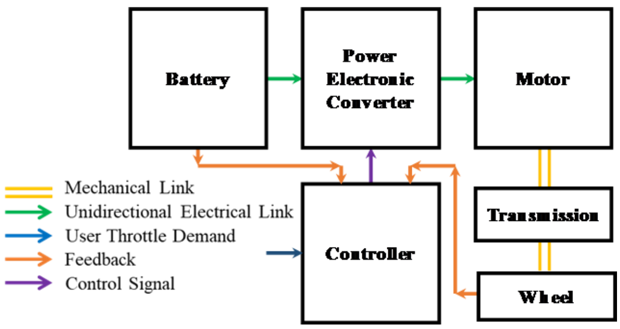

Fig. 1.Pure Electric Propulsion Architecture

B. E-Bike Utilization

Based on the utilization, the e-bike can be classified into four broader categories as listed and explained below

- City / Urban e-bike
- Racing e-bike
- Hill Climbing e-bike
- Commuting / Distance e-bike

In these models, the average speed, power rating and ranges vary. The city / urban e-bike require fast acceleration, frequent stops to manage the traffic and for smooth driving. The average power consumed by the e-bike is 150W.The average speed achieved in the urban area is 17.6 km/hr.

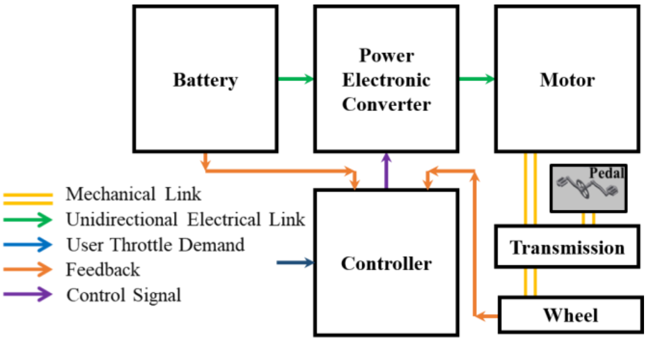

Fig. 2.Pedal + Electric (Pedaelec) Propulsion Architecture

The racing variant e-bike requires faster accelerating ability, average speed of around 29km/hr with an average power consumption of 200W. Hill Climbing e-bike requires high torque capability for climbing slopes in a hill. The maximum power consumed 300W at 12.8 km/hr for a short time corresponding to four percent slope grade. Commuting / Distance e-bike is designed for travelling at a constant and lower speeds for a longer distance [5].

C. E-Bike Powertrain

Based on the position of the motor drive mechanism, the following are the e-bike variants

- External motor drive mechanism
- Hub motor drive mechanism
- Frictional motor drive mechanism

Fig. 3.External motor with chain link (Source: L-faster)

All these motor drive units are designed to be water resistant. The propulsion motor transfers the power to the wheel through a chain mechanism as shown in Fig. 3. This type of configuration is easy for maintenance. If the motor is attached to the main power train (i.e. motor is attached to the pedal shaft), then the e-bike performs as a pedaelec model giving the user more flexible control and the motor torque can also be varied using the gears and controls. The center of balance is low giving greater control to the user. The disadvantage is complexity of the system [6]. Literature survey has conveyed that the performance and cooling of such powertrain system was found better than the rest of the two powertrain configuration. In Hub motor drive mechanism (Fig. 4), the motor is a part of the wheel (either rear or front wheel). Main disadvantages are uncontrollable drift at the front wheel can lead to catastrophic disaster. If the hub motor is attached along the rear wheel it will add high frictional area along the rear due to the added weight this kind of bikes are useful in hilly areas. The installation of the motor is complex and the system can be integrated only into the light weight cycles for better efficiency [5], [7]. It has slightly higher maintenance issue than External motor drive mechanism.

Frictional motor drive mechanism (Fig. 5) produces high amount of heat and the performance of the system depletes during rainy situation. The main disadvantage is tire gets burn our easily due to the frictional contact [7].

Fig. 4.Hub motor drive (Source: UU Motor)

Fig. 5.Frictional motor drive (Source: ebikeschool)

D. E-Bike Electric Propulsion

As mentioned earlier, the motor acts as the propulsion source. There are three different motors primarily used for generating the propulsion force.

- Brushed DC series motor
- Permanent magnet DC motor
- Brushless DC motor

Brushed DC series motor is one of the common motor which has the highest starting torque. The series field coil and the armature coil of the motor are connected in series. The interaction between the flux produced by the series field coil and the main armature coil result in the necessary generation of torque. The supply is altered in the armature coil by the commutator, thus the motor

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shaft rotates in an axis. Due to the commutator arrangement, operating the motor at higher RPM is not advisable. The control of the motor is achieved with a normal DC to DC converter. Comparatively the cost of the motor along with the converter is found cheaper than other available options, but the efficiency is comparatively low.

PMDC motor uses permanent magnet as the field coil to produce the necessary flux. The part of the main armature coil is energized by external DC supply at a time. Since the motor uses a permanent magnet, the speed control is possible by controlling the main armature current. As this motor uses only half the amount of copper when compared to DC Motor, it costs cheaper than the former one.

BLDC motor uses permanent magnet as the rotating field and also uses several coils for producing the required field flux when energized. This motor requires a separate control module for continuous opeartion. Position sensing is required to determine for proper energisation of the coil. This motor is high efficient in high speeds. The position of the rotor needs to be determined for control process. The control system for BLDC is complicated and costlier as it requires additional sensors. Table I gives the comparison detail of the above mentioned motors.

Table- I: Motor Specification

Parameters	Symbol	DC Series	PMDC	BLDC
Power	*P*	250	250	250
Speed	*N*	300	400	350
Voltage	*V*	24	24	36

The speed of the motor mentioned here is after speed reduction with suitable gears. Table 2 presents the comparison of the e – bike models available in the market. The propulsion power for these models are achieved by BLDC Hub motor.

Table- II: E-Bike Specification

Parameters	Model 1	Model 2	Model 3
Power Rating	250 W		
Torque	32 NM		
Voltage	36 V		
Sensors	12 Magnet Dual Hall PAS		
Battery Type	Li -on		
Weight	25 kgs		
Rating	10.4 AH	7.8 AH	10.4 AH
Charging Current	3 A	3 A	5 A
Utility Type	Urban & off Road	Urban	Off Road

III. BLDC Drive Based E-Bike Propulsion System

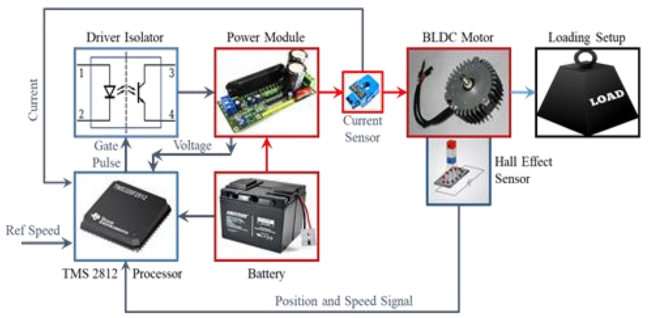

Fig. 6.Block Diagram of BLDC beased E-Bike Test Rig

Fig. 6 shows the block diagram of the experimental set up used for determining the performance of the BLDC motor.

The position of the rotor is sensed by Hall Effect sensor. This sensor uses magnetic flux to determine the position of the wheel by allowing voltage to pass through it when the magnetic flux is perpendicular to the hall sensor. The present setup uses three such sensors to determine the position of the rotor as well as for the speed measurement. The sensors are connected with a supply of +5V, this will generate a square pulse of a frequency directly proportional to the speed of the motor at which it is operating. This signal is taken into consideration for energizing the phase of the main coil.

The technical specification of the BLDC motor is presented in Table 3 [8].

Table- III: BLDC Motor Specification

Parameters	Ratings
Poles	4
Speed	4600 rpm
Current	4.52 A
Torque	3.5 Nm

TMS320F2812 is used as controller for the BLDC motor. The speed and aspect of this DSP makes it a finest option for digital controlling of motors [9]. The block diagram represents the speed control of BLDC motor using TMS320F2812. This controller performs faster to process a control parameter and calculation will be computed promptly [8]. Power Module is designed for motor control applications using IGBT & DIODE technology. Mitsubishi Intelligent Power Modules (IPM) is used as a power drive unit. It has various protection systems that can prevent the drive from damaging from external and internal faults. It has six IGBT and the gate of the IGBTs are controlled by internal firing circuits and the feedback of the processor can be given to control the motor. The output of the IGBTs are connected to the motor [10].

IV. Laboratory Setup for Testing BLDC Motor and Testing Methodology

A. E-Bike Configuration Considered

The weight of the e-bike with the rider is considered to be 80 Kg riding on a grading of 0 percentage. Based on the regulations provided in CMVR, for a non-licensed category of E-bike, the power should not exceed 250W, with a maximum speed restricted below 25km/hr.

B. Experimental Setup

Fig. 7. Experimental Setup

Fig. 7. Presents the experimental setup of the BLDC Motor under test. The input parameters like DC Voltage, Current, Power along with the output parameters like, Phase Voltage, Current, Motor Speed, Torque etc., are tabulated. The speed of the motor is varied by changing the duty ratio of the converter used for powering the BLDC motor.

To determine the suitable speed of operation of the motor to match the speed restriction given by the competent regulating authorities and then determine the related motor specifications, the parameters (Table IV) with certain range variation have been considered.

Table- IV: Parameter and its Range

Parameters	Range	
	Min	Max
Duty Ratio	0.12	0.44
Load Current	0.25	3.5
Speed	250	4500
Torque	0	2

C. Testing Methodology

The speed of the motor is set by changing the duty ratio of the converter. Table V presents the speed of the motor at no load along with the corresponding duty ratio. A total of 6 such cases have been considered

Table- V: Motor Speed and Converter Duty Ratio

Case	Motor Speed	Duty Ratio
1	750	0.12
2	1000	0.16
3	1500	0.24
4	2250	0.31
5	2750	0.40
6	3750	0.44

For each case, the load torque for the motor is varied in terms of load current (0.3, 0.5, 1, 1.5, 2, 2.5, 3, 3.5 amps).

The motor is made to run at a particular rpm and the load is increased from 0. After the experimentation, the graphs between various parameters have been plotted to arrive at optimal operating point of the motor which yields to better torque and range.

V. Results and Discussion

As mentioned earlier, the permitted power for E-bike without licences is 250W, the same has been taken as base evaluation factor. The torque vs motor power for different duty ratios have been plotted as graph and presented in Fig 8. On drawing a refence line at 250W, the maximum torque of 1.52 Nm is being delivered by the motor when it is operated at a duty ratio of 0.4.

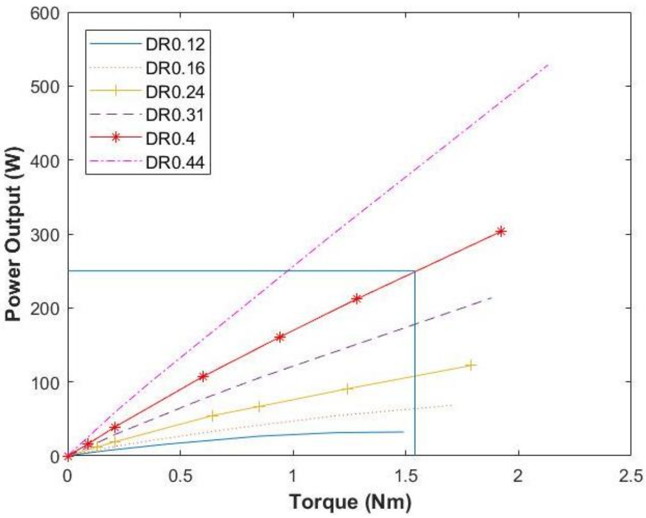

Fig. 8. Torque vs Mechanical Power Output

On further plotting the graph between Torque and Current (Fig. 9), it is found that the motor runs at a current of 3 amphere to deliver a power of 250 W at 1.52 Nm.

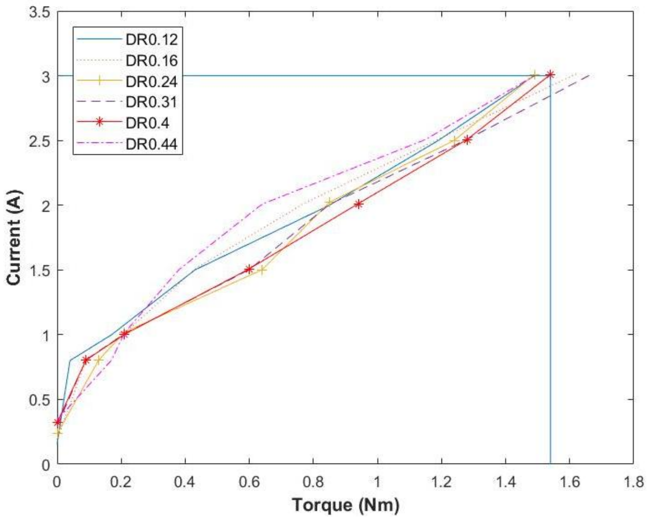

Fig. 9.Torque vs Current

The speed of the motor at this condition is found to be around 1550 rpm (Fig. 10).

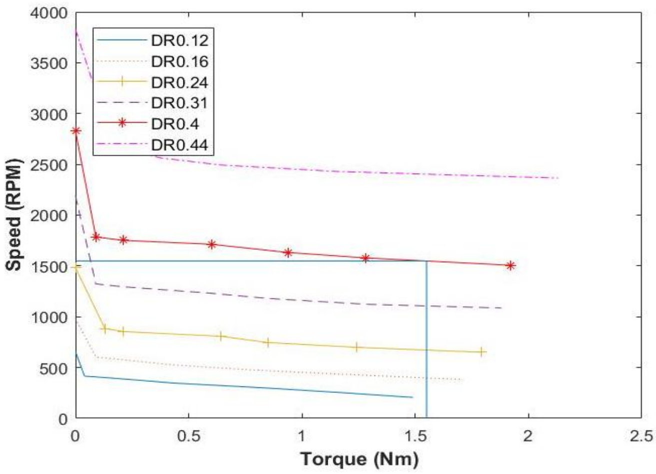

Fig. 10. Torque vs Speed

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VI. E-BIKE RANGE ESTIMATION

If an E-bike with a maximum speed of 25 km/hr and a wheel diameter of 0.6604 mts is used, then a gear ratio of of 7.75 will be required to match the rpm and torque of the motor with the torque demand and the maximum speed of the vehicle in km/hr.

In case, if the motor is powered from a 10.4 AH battery, the vehicle can run for 3.4 hrs approximately at the rated current. The total distance that could be covered will be around 85 kms. The range mentioned for the existing models are less than this range. The motor rotates at a speed of 1550 rpm (Fig. 10) @ 1.52 Nm.

VII. CONCLUSION

The need and the architecture discussion for e-bike has been presented. The performance of the BLDC motor for the e-bike application was examined with the help of laboratory experimentation. Based on the results obtained, if the motor is operated at with a duty ration of 0.4, the motor would be running at 1550 rpm delivering 1.52 Nm. A rear ratio of 7.75 is required to match the speed and torque demand of the E-bike with the torque demand and the speed regulation given by CMVR. The distance travel / charge is around 85 km with a battery capacity of 10.4 Ah which would be higher than few of the existing models available in the market.

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Prof. Paul Sathiyan has obtained his Doctoral degree from Karunya Institute of Technology and Sciences and currently working on Electric and Hybrid Vehicles. He has a vast research experience over 8 year in the areas related to Electric Vehicles, Power Converters, and Optimization techniques applied to Advanced Driver Assistance Systems. Currently he is associated with Department of Electrical and Electronics Engineering, Karunya Institute of Technology and Sciences, Coimbatore.

Prof. C. Benin Pratap has obtained his Master’s degree in the area of Power Electronics and Drives from Anna University, Chennai and currently pursuing his research and associated with Department of Electrical and Electronics Engineering, Karunya Institute of Technology and Sciences, Coimbatore. He has a good research experience in the area of special machines, Electric Drives, Multi-level inverters and Solar PV system.

Daniel has obtained his undergraduate degree in the field of Electrical and Electronics Engineering from Karunya Institute of Technology and Sciences, Coimbatore. His research interest are in the area of Electric Vehicle technology and Power Electronic converters.

Arun has obtained his undergraduate degree in the field of Electrical and Electronics Engineering from Karunya Institute of Technology and Sciences, Coimbatore. His research interest are in the area of Electric Vehicle technology and Power Electronic converters.