

Study on Hub Motor & Design of Uni-Wheel Bike

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ABSTRACT: A uni-wheel bike is a one wheeled single-track vehicle powered by a hub motor. The main aim of uni-wheel is that it reduces the space occupied when a single occupied vehicle is necessary and environment friendly. The rider sits on the top of concealed wheel included by a motor driven mechanism. This vehicle follows gyroscope technology as working principle. The motor driven mechanism includes mainly a hub motor which is of Brushless DC motor type driven by a motor driver circuit and battery backup for self-starting. As an on-road vehicle, the speed control is necessary, and it is achieved by using electronic circuitry incorporated in the motor driver circuit. Also, Brushless DC motor offers more torque to weight ratio and increased efficiency compared to Brushed DC motors. All these parameters considered, a design of uni-wheel bike is planning with a prototype. Design and analysis of this project is going to be done with standard software's available.

KEYWORDS: BLDC Motor, Hall Effect Sensors, E- Vehicle Speed Controller, Solid Works Modelling

I. INTRODUCTION

Studies on battery electric vehicle or simply E-Vehicle shows that it's a better solution for maintaining an ecofriendly and economical transportation. Battery Electric Vehicles are generally of two types viz a wheel driven by motor powered by battery which is mounted outside the wheel and a wheel driven by Brushless DC motor powered by battery in which the motor is rugged within the wheel itself called as HUB Motor. Among this Brushless DC motor-based wheel driven mechanism are now trending.

BLDC motors are widely used in industries due to its advantages. The application of BLDC motors is increasing due to consumers demand for lower energy costs, better performance and reduced noise. Also, the use of BLDC motors is restricted in low cost applications comparatively, which paves the way to reduce the cost related issues for E-Vehicle.

The space utilized by each vehicle in public roadways are now in its peak since the demand for individual commuting is moving to its maximum. The sustainability and access to public transports is also an issue in future. So, a space effective, reliable and ecofriendly solution for transportation is needed. A BLDC driven Hub motor based mono wheel bike is planning to design which is a best solution for space utilization if a single person is in need to commute.

II. SCOPE OF THE E- VEHICLE

High traffic congestion in urban areas due to people's commuting increases the air pollution and less effective space utilization in roads. Also, rapid depletion of petroleum products increases the need of other technology-based innovations to make the traffic easier and effective. The recent studies show that technological improvement in conventional fuel sources are not as fast as that in electric vehicle-based techniques. Even though E-Vehicles are available from mid-19th century, the boom for E-vehicles started only in 21st century with advancements in solid state electronics. On concern with the problems incurred on hydrocarbon-based fuel vehicles, the need for Battery Electric Vehicles –BEV is now at its peak demand. Power Electronics based BEV is a better solution now a days due to availability of cheaper and reliable constituents. Our studies include the following sections to understand the mode of E-vehicle propulsion.

1. To study the scope of E-Vehicle in future.
2. To learn the basics of Brushless less DC motor and its advantages.
3. To study the incorporation of BLDC motor as hub motor.
4. To assemble a prototype of hub motor driven single wheel e-vehicle.

III. ABOUT BLDC MOTORS

A brushless DC electric motor (BLDC motor), also known as electronically commutated motor (ECM or EC motor) or synchronous DC motors, asynchronous motors powered by direct current (DC) electricity via an inverter or switching power supply which produces electricity in the form of Alternating Current (AC) to drive each phase of the motor via a closed loop controller. The controller provides pulses of current to the motor windings that control the speed and torque of the motor. BLDC motors are widely used in industries due to its advantages. The use of BLDC motors is restricted in low cost applications. Major appliances include washing machine, room air conditioners, refrigerators, vacuum cleaners, freezers etc.

The trending application of BLDC motors includes drones, computers and automobile industry which require low cost, less weighing mode of motoring in various sections of it. Currently E-Vehicle or Battery Electric Vehicle needs a motor driven wheel mechanism which completely avoids the use of fossil fuels. E-Vehicle requires a Hub Motor to drive the wheel. The hub motor can be installed in two wheel or four-wheel drive mechanisms.

Several studies reveal that the BLDC motor is more suited to use as a hub motor. Also, these motors are utilized in many low and medium power applications. Unlike a DC motor these brushless motors have permanent magnet as rotor and stator consists of three phase concentrated windings. As the name suggests, it is a brushless motor which has the characteristics of a DC motor. This synchronous motor is electronically commutated, for which the exact rotor position is required hence the losses associated with brushes such as sparking, and wear and tear of commutator is eliminated. The rotor position can be determined by using hall effect sensors. For a BLDC motor drive, the power circuit consists of a diode bridge rectifier and a voltage source inverter for electronic commutation of the stator winding.

IV. CONSTRUCTION OF HUB MOTOR

Conventional BLDC motors are coming with permanent magnets fixed on rotor part and three phase AC windings wound on stator part of motor. But the main requirement of Hub motor is that the three phase AC windings should be placed fixed at the stator and permanent magnet should be fixed on rotor part. This type of arrangement reduces the winding requirements of AC windings.

The Hub or wheel drum is fixed over the rotor part of the motor, so that the rotation of the rotor enables the wheel to move. The BLDC type Hub motor is supplied from a battery bank in case of E-Vehicle. But the BLDC motor works on the principle of three phase synchronous motor, which requires three phase AC supply inside it and also windings are wound over stator part of the motor, which is coming as the inside part of the motor. So, a three phase AC inverter network is required to perform the conversion of supplied DC power to three phase AC power, this can be done through three phase inverters.

The main problem in the operation of the BLDC type motor is that it lacks the presence of commutator. The role of commutator in a DC motor is to reverse the direction of armature current in the brush zones so that the torque will be unidirectional. But in hub motor, the unidirectional torque can be generated by means of using hall sensors. Construction of BLDC Hub motor includes mainly the following parts,

1. Rotor part with fixed permanent magnet on it.
2. Stator part with AC windings are wound.
3. Motor driver circuit.
4. Battery Bank from which motor is supplied.



Fig 1 : BLDC HUB Motor and its parts

V. BLOCK DIAGRAM OF BLDC HUB MOTOR

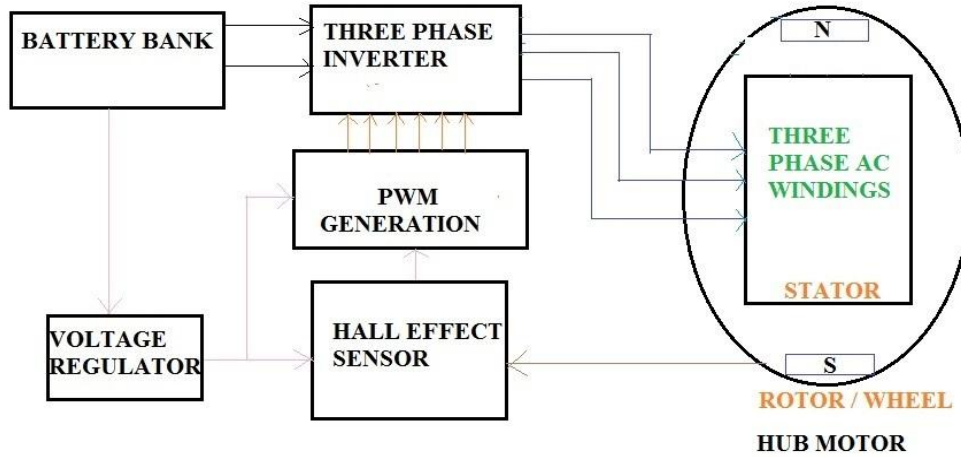


Fig 2 : Block Diagram

VI. CONCEPT OF HALL EFFECT SENSORS

Hall Effect sensors are basically linear transducers that are used to measure the magnitude of magnetic field. It consists of basically a thin piece of rectangular P-type semiconductors material made from Gallium Arsenide (GaAs), Indium Antimonide (InSb) or Indium Arsenide (InAs) passing a continuous current through itself. Hall Effect principle says that when a conductor or semiconductor with current flowing in one direction is introduced perpendicular to a magnetic field, and then a voltage could be measured at right angles to the current path. The effect of getting measurable voltage as told above is called as the Hall Effect and voltage such formed is called as hall voltage. In short, this hall sensors generate a hall voltage when a magnetic field is detected which is used to measure the amount of magnetic flux density. Hall sensors are introduced in hub motor to detect the position of rotor or it is called as rotor position sensors. They produce very low-level signal as output and so it requires amplification. The presence of distributed electrons over the substrate can concentrate along a straight-line path when a magnetic field is detected.

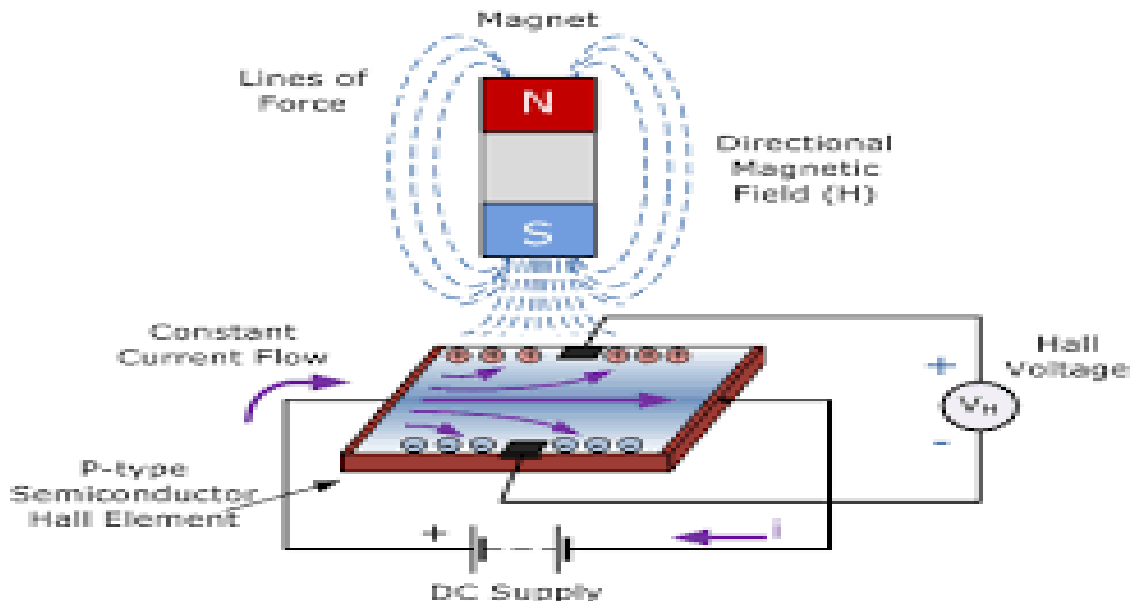


Fig 3: Working of Hall effect sensors

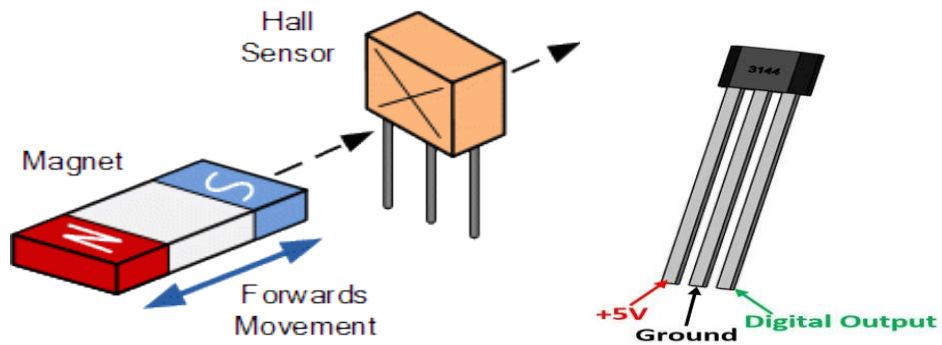


Fig 4 : Interaction of Magnetic field with Hall sensors

Fig 5: Pin diagram of Hall Sensors

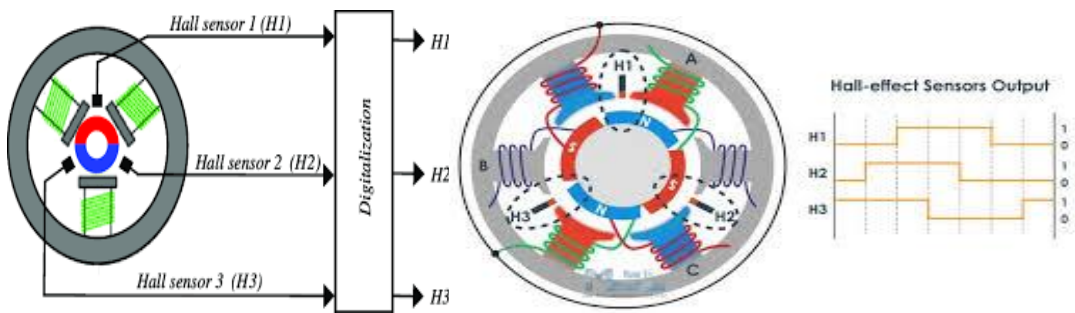


Fig 6 : Digitization of Hall sensor output

Usually the hall sensors are placed on the rotor part of the motor in which AC windings are wound and permanent magnets are placed in the stator part of the motor. But it is reversed in case of hub motor so that stator windings are placed along with the hall sensors and rotor part that is outer hub is fixed with permanent magnets on it. The accuracy of the hall sensor effect can be improved by placing individual sensors for each three-phase winding.

The rotation of the rotor section can be enabled by the use of commutator and brushes the brushes charges the commutator inversely in polarity to the permanent magnet, in turn causing the armature to rotate. But in BLDC hub motor, the whole process will be done with the help of hall sensors in conjunction with PWM generating circuit.

VII. ABOUT MOTOR CONTROLLER

Motor controllers are used to control the speed of motor by a closed loop controlling mechanism. Also, Brushless motors are not self-commutating, and hence are more complicated to control. This motor control requires knowledge of the rotor position and mechanism to commutate the motor. The closed loop controller provides the measurement of rotor speed and motor current and produces PWM signal to control the motor speed and power. Most applications, that only require variable speed operation, will use six independent PWM signals. Hall Effect sensors use in BLDC motors to provide absolute position sensing. Different types of control algorithms have been used to provide control of BLDC motors. The motor voltage is normally controlled using a power transistor operating as a linear voltage regulator. This is not practical when driving higher-power motors. High-power motors use pulse width modulation control and require a microcontroller to provide starting and control functions.

The control algorithm must provide three things:

1. PWM voltage to control the motor speed
2. Mechanism to commutate the motor

3. Method to detect the rotor position using Hall Sensor arrangement.

Pulse-width modulation technique is in use now a days to apply a variable voltage to the motor windings. The effective voltage is in proportion to the PWM duty cycle. When properly commutated, the torque-speed characteristics of the BLDC motor is similar to a dc motor. The speed of the motor and the available torque can be controlled by the variable voltage. Trapezoidal signals are produced as controlling signals, in which two windings are energized at a time and the third winding is not energized. As the motor turns, the current to the motor terminals is electrically switched (commutated) every 120° of rotation. The controller should be installed at a position which is away from the ground as far as possible. The opening of the controller should be downwards to prevent water from coming into the controller. The most common configuration for sequentially applying current to a three-phase BLDC motor is to use three pairs of power MOSFETs arranged in a bridge structure, as shown in Figure 2. Each pair oversees the switching of one phase of the motor.



Fig 7 : BLDC Motor Speed Controller

VIII. WORKING OF THE HUB MOTOR

The working of BLDC motor is different from conventional DC motor, in which the uniform torque and rotating magnetic field is created by commutator and brush arrangement, whereas in BLDC motor input DC voltage supplied to the motor is converted into corresponding AC by inverter circuits and it is fed into the AC windings so that the rotating magnetic field is created and it is called as electronic commutation. This magnetic field will interact with magnetic field created by the permanent magnet to induce a voltage in the winding so that the rotation can be enabled. The windings used for making stator windings are made from laminated copper wires and the rating of material used may selected depends on the power rating of the motor and current flow through the conductor. The hub motor requires rotor part as the external part to fix the wheel drum and DC supply from the battery bank is given to stator part of the motor through motor driver circuit. The motor driver circuit consists of pulse generation part. The pulse generated is purely depends on the output from the hall sensors. A three-phase voltage source inverter is used to convert the DC supply from the battery bank to corresponding AC supply. The rotation of the BLDC motor can be enabled only by this mechanism. The wave winding technique is adopted in BLDC motor since it is a high voltage (500-600V) and low current (around 5A) machine. For a given number of poles and armature conductors wave winding gives more emf than that of lap winding.

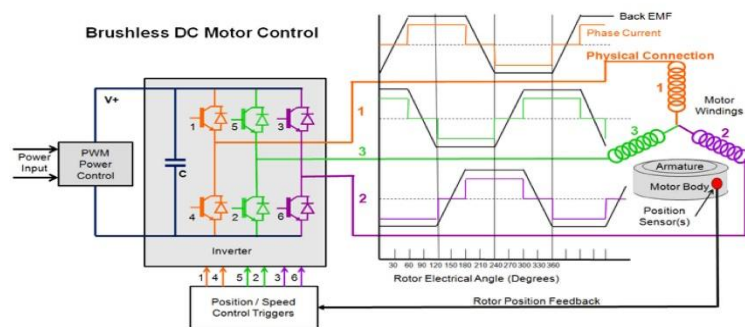


Fig 8 : BLDC Motor Working Diagram

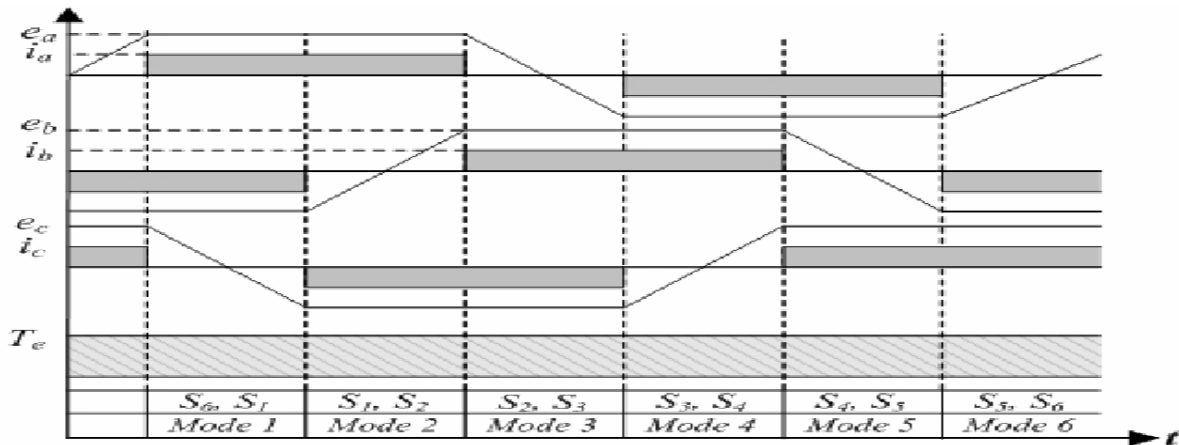


Fig 9 : Waveforms of trapezoidal back emf, stator currents and uniform torque production

IX. CASE STUDY & PLATFORMS USED IN DESIGN

- 1. STP (gross hopp)- torque calculation
- 2. E- bike simulator
- 3. DC motor power calculator
- 4. Easy calculator.com
- 5. Wen technology
- 6. Solid works

CASE STUDY ON HUB MOTOR

Motor type – 60 Volts, 1000W
 Battery – lithium ion battery, 60volts, 4.4A
 Max. Speed – 22MPL (35.4km/Hr)
 Wheel Rim Dimension – 10”

RPM CALCULATION ON WHEEL

Speed Torque Calculation (Wen Technology)
 Speed S = 35.4 km/hr= 590 m/min
 Diameter of Wheel Rim = 10”= 0.254m
 Diameter of Wheel D = 49 cm = 0.49m
 Distance per revolution of wheel = πD= π * 0.049 = 1.54m
 Revolution per minute of wheel N = speed / distance per revolution of wheel= 590/1.54 = 382 RPM

VEHICLE DYNAMICS

To decide the power rating of a vehicle, the vehicle dynamics like rolling resistance, gradient resistance, aerodynamic drag, etc. has to be considered. For illustration procedure for selecting motor rating for an electric bike of gross weight 120 kg is considered.

The force required for driving a vehicle is calculated below,

$$F_{total} = F_{rolling} + F_{gradient} + F_{aerodynamic\ drag}$$

Where, F_{total} =Total force

- $F_{rolling}$ = force due to Rolling Resistance
- $F_{gradient\ resistance}$ = force due to Gradient Resistance
- $F_{aerodynamic\ drag}$ =force due to aerodynamic drag

F_{total} is the total tractive force that the output of motor must overcome, in order to move the vehicle.

ROLLING RESISTANCE

Rolling resistance is the resistance offered to the vehicle due to the contact of tires with road. The formula for calculating force due to rolling resistance is given by equation: $F_{rolling} = Crr * M * g$

Where,

- Crr= coefficient of rolling resistance
- M= mass in kg
- g= acceleration due to gravity= 9.81 m/s²

For the application considered,
 $C_{rr}=0.004$ $M= 120\text{kg}$
 Therefore, $F_{\text{rolling}}= 0.01*120*9.81= 4.8\text{N}$

GRADIENT RESISTANCE

Gradient resistance of the vehicle is the resistance offered to the vehicle while climbing a hill or flyover or while travelling in a downward slope.

The formula for calculating the gradient resistance is given by equation:

$$F_{\text{gradient resistance}} = M * g * \sin \alpha$$

In this illustration, let us consider the electric bike runs on a flat road. Therefore, the angle $\alpha = 0^{\circ}$.

$$F_{\text{gradient}} = 120 * 9.81 * \sin 0^{\circ} = 0 \text{ N.}$$

In this case, the power required to overcome gradient resistance is also zero

AERODYNAMIC DRAG

Aerodynamic drag is the resistive force offered due to viscous force acting on the vehicle. It is largely determined by the shape of the vehicle. The formula for calculating the aerodynamic drag is given by equation:

$$F_{\text{aerodynamic drag}} = 0.5 * C_A * A_f * \rho * V^2$$

These are the three main forces which act on the vehicle when it travels at constant speed. While accelerating and decelerating the effect of force due to inertia also acts. In this illustration, let us consider the power required to overcome Aerodynamic drag is follows,

Velocity $v = 8.8 \text{ m/s}$ Frontal surface Area $A_f = 0.6\text{m}^2$ (approximated) Density of Air $\rho = 1.225\text{kg/m}^3$

Drag coefficient of bike = 0.9

$$\text{Therefore, } F_{\text{aerodynamic drag}} = 25.613\text{N}$$

Therefore, the total tractive force required to move the vehicle is

$$F_{\text{total}} = 30.413\text{N}$$

X. DESIGN OF UNI WHEEL E-BIKE USING SOLID WORKS

Solid works is a solid modelling computer-aided design computer program that runs on Microsoft Windows. Solid Works is a solid modeller. It utilizes a parametric feature-based approach which was initially developed by PTC (Creo/Pro-Engineer) to create models and assemblies. The software is written on Parasolid-kernel. Parameters means values determine the shape or geometry of the model or assembly. Parameters can be either numeric parameters (line lengths or circle diameters), geometric parameters (tangent, parallel, concentric, horizontal or vertical, etc). Numeric parameters can be associated with each other using a relation, which allows them to capture design intent.

Building a model in Solid Works generally starts with a 2D sketch even though 3D sketches are available for power users. The sketch consists of geometry such as points, lines, arcs, conics splines and except the hyperbola. Dimensions are added to the sketch to describe the size and location of the geometry. To define attributes such as tangency, parallelism, perpendicularity, and concentricity the relations are used. Finally, drawings can be created from parts and assemblies. Views can be automatically generated from the solid model and the notes, dimensions and tolerances can be easily added to the drawing as needed. The drawing module includes most paper sizes and standards like ANSI, ISO, DIN, JIS, BSI and SAC.

SOLID WORK MODEL OF E-VEHICLE

Model prepared using solid works as follows.



Fig 10: Solid Works 3D Modelling of Uni-wheel Bike

DISMANTLED HUB MOTOR FOR CASE STUDY

Fig 11: Rotor Or Wheel, Stator and Hall Sensor part of Romai 60 V , 1000W Hub Motor

XI. CONCLUSION

The boom in single wheel e- vehicle is now trending everywhere in the world. But in India, it is still in budding area. The main drawback discussed by the researches is on its total cost incurred. Based on the case study for understanding working of hub motor, it is evident that a 60V, 1000 W hub motor can be driven by using a lithium ion battery bank which gives voltage output in the range of multiples of 12V basic battery output. However, the researches in the battery bank and its constituents is on the way to reduce the area occupied or simply rugged in construction. The cost related issues of any type of E-Vehicle depends on the overall expenses on battery bank. The advantages of BLDC motors over conventional motors are valued. The concept of Hall effect sensors and its use in BLDC motors are interesting. Conventional BLDC motors are coupled with windings outside and permanent magnets tend to rotate in the electromagnetic field. It is the main feature of this hub motor that the permanent magnets are coupled on the rotor and windings are in stator. The design using solid works gives a 3D modelling of uni-wheel bike which gives easy way to design in future.

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