ISSN No:-2456-2165

Design of a Hybrid Bicycle with Regenerative Braking using BLDC Motor

Vipul Shridhar Wadkar, Shridhar Uddhavrao Kale
Electrical Engineering Department
Walchand College of Engineering, Sangli

Abstract:- Design of a Hybrid Bicycle is presented in this paper. The basic aim behind the design is to reduce the burden on conventional fuels and to promote use of bicycles. With innovative regenerative braking system energy usage efficiency can be improved. Brushless dc (BLDC) motor is used because of its high power density, high torque to weight ratio. Also BLDC motor offers better speed torque characteristic, high efficiency, wider speed range, and requires less maintenance. A controller is designed for the BLDC motor using IC MC33035, its configuration is also given in the paper. The controller is designed using ORCAD software. After analyzing the simulation results the practical implementation is done.

Keywords:- *Hybrid Bicycle, Brushless dc (BLDC) motor, regenerative braking, BLDC motor controller.*

I. INTRODUCTION

The increasing consumption of fossil fuels has resulted a massive hike in its costs which is a matter of concern to the economy. Recently, electric bicycles have received much attention as an alternative to conventional motor vehicles for travelling to shorter distances. With the progress in motor and battery technology, the hybrid bicycle can be considered as good alternative to the vehicles. A hybrid electric bicycle has two types of energy storage units, electricity and human power. Electricity means that a battery is used to store the energy, and that motor will be used as traction motor. Regenerative braking can be used in hybrid bicycles to recycle the brake energy, which is not possible in the traditional bicycle. Regenerative braking is the process of feeding energy from the drive motor back into the battery during the braking process when the vehicle's inertia forces the motor to operate into generating action. When the battery is fully charged the energy is dissipated in resistive load so the braking is affected. Therefore, hybrid bicycle still needs a mechanical brake for safety actions.

The use of bicycle has been reducing day by day because of the extra efforts required in comparison with motor bikes and the low speed of transportation. A rider has to produce a lot of energy to ride a bicycle especially when going uphill, this can be tiresome. The extra efforts required for riding bicycle when going uphill or riding against headwinds can be reduced by using Hybrid cycle which will assist the rider by supplying extra power required with help of BLDC motor supplied through battery. So, the use of bicycle for commuting to nearby places can be encouraged.

II. MOTOR AND CONTROLLER

A. Selection of a Motor

Brushless Direct Current (BLDC) motor is a type of synchronous motor, where magnetic fields of both stator and rotor rotate at the same frequency. The BLDC motor offer longer life with low maintenance because no brushes are required. Also, it has a high starting torque, high no-load speed and small losses.

The BLDC motors are available in single-phase, two-phase, and three-phase. Three-phase motors are the most popular among all the configurations and are widely used in hybrid bicycles.

There are two parts in structure of a BLDC motor:

- Moving part called as rotor, represented by permanent magnet
- Fixed part called as stator, represented by phase windings of magnetic circuit

➢ *Stator*

The stator of a BLDC motor consists of stacked steel laminations with windings placed in the slots that are axially cut along the inner periphery.

➢ *Rotor*

The rotor is made of permanent magnet and can vary from two to eight pole pairs with alternate North (N) and South (S) poles. BLDC motor can be controlled electronically using microcontroller. For the operation of BLDC motor, the stator windings needs to be energised in a particular sequence.

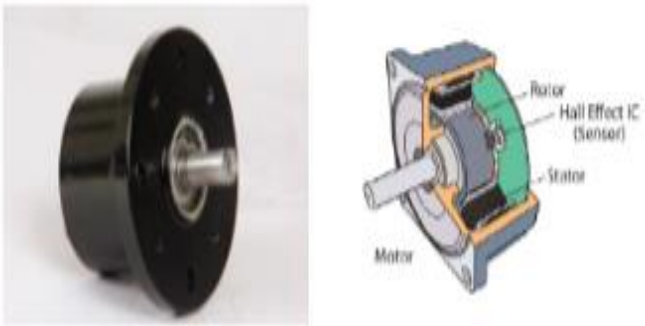

Fig 1:- Basic construction of BLDC Motor

Hall Effect sensors are embedded in the stator to sense the rotor position. From the known rotor position, it is understood which winding to be energized next. Most BLDC motors have three Hall sensors embedded in the stator on the non-driving end of the motor. Whenever the

rotor magnetic poles pass near the Hall sensors, they generate a high or low signal, which indicates that N or S pole is passing near the sensors. Based on the combination of these Hall Sensor signals, the exact sequence of commutation can be determined.

B. Power Calculations for Selection of Motor

The total power Ptotal required to drive the bicycle ican be given as the sum of the power to overcome the slope Phill, power to overcome the air drag Pdrag, and the power to overcome the friction Pfriction. Mathematically it can be represented as,

$$Ptotal = Pdrag + Phill + Pfriction$$

$$Pdrag = ((Cd.D.A)/2) * (Vg + Vw)^2 * Vg$$

$$Phill = 9.81 * G * Vg * m$$

$$Pfriction = 9.81 * m * Rc * Vg$$

Fig 2:- Forces on bicycle

D is Density of air in kg/m^3
A is Frontal area in m^2. The frontal area is the area of the mass encountered by the air.
Typical values of frontal area are
A = 0.4 m^2 to 0.5 m^2
Cd is Drag – The drag coefficient is small for aerodynamic bodies
Typical values of drag coefficient are:
Passenger car: *Cd* = 0.3, upright Cyclist: *Cd* = 1 and *Cd* = 0.5 for cyclist
Vg is Ground speed in m/s
Vw is Head wind speed in m/s
G is Slope grade
m is Weight of the rider in kg
Rc is Rolling Coefficient – The rolling coefficient changes with friction effect.

Calculations are done for riders of different weights. So, BLDC motor of 24 V, 400 W is selected for the project. With increase in the torque requirement, speed of the BLDC motor falls. Efficiency of the motor increases slowly with speed and is maximum at speed around 1600 rpm and torque is approximately 14 Nm. Torque produced by the motor at the shaft increases with increase in load. Maximum of 22 Nm torque is required at highest gradient of 6% grade.

III. CONTROLLER DESIGN

BLDC motor controller is designed by using IC MC 33035, IRF3205, IR2103 and controller circuit is prepared by using ORCAD software. This device has a rotor position decoder for proper commutation sequencing, frequency programmable saw tooth oscillator, three open collector top drivers, and three high current totem pole bottom drivers ideally suited for driving power MOSFETs. There are options for control of motor operations such as open loop speed, forward or reverse direction rotation and dynamic braking. The MC33035 operates with electrical sensor phasing of either 60°/300° or 120°/240°, and can be used to control the brushed DC motors. Suitable drivers IR2103 and other are used to drive the MOSFET, IRF3205. Controller circuit prepared is as shown in the figure below.

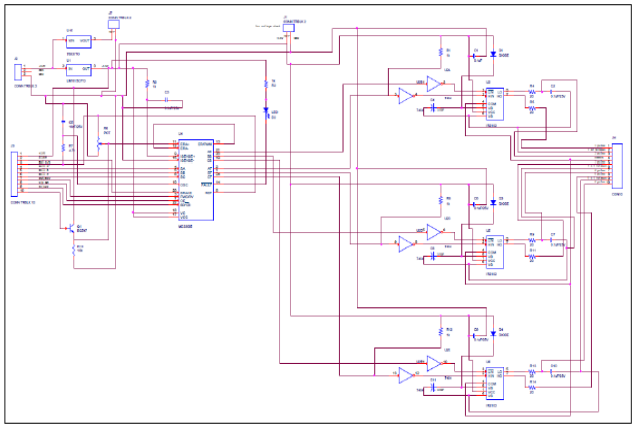

Fig 3:- Controller circuit design in ORCAD

IV. BASIC METHODOLOGY AND DESIGN STEPS

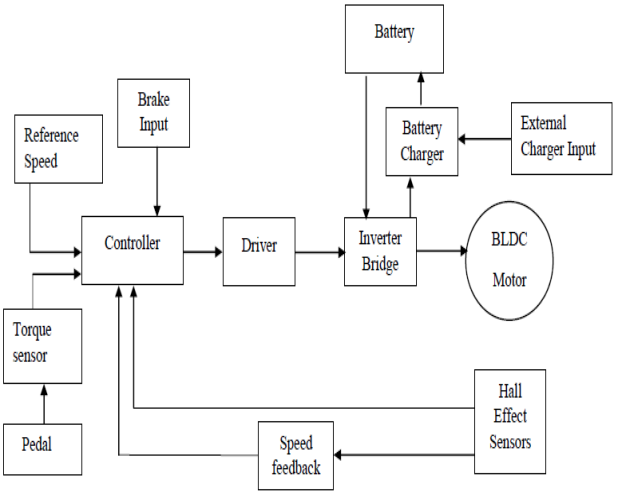

Fig 4:- Basic block diagram of the project

Inverter Bridge is used to convert input DC supply into three phase ac supply. Hall Effect sensor is used as a speed feedback given to the controller. The input to the controller is reference speed and torque, and actual speed and torque, from which the controller calculates the actual power and reference power. And controller takes the action of either motoring or regenerative braking. Separate brake

input is provided in case of emergency stop. Driver circuit is used to amplify the signals from the controller to be given to the MOSFET's of the inverter bridge. In case of battery gets fully discharged, external charge inputs are provided to the battery. By sensing the speed i.e. by counting the number of pulses from Hall Effect sensor, and torque through torque sensor which will be located at pedal, Controller will get idea of power required. That will be compared with reference power which is obtained from reference speed and torque. Accordingly, controller takes the action of either motoring or generating and gives the switching signals to driver corresponding with Hall Effect sensor values.

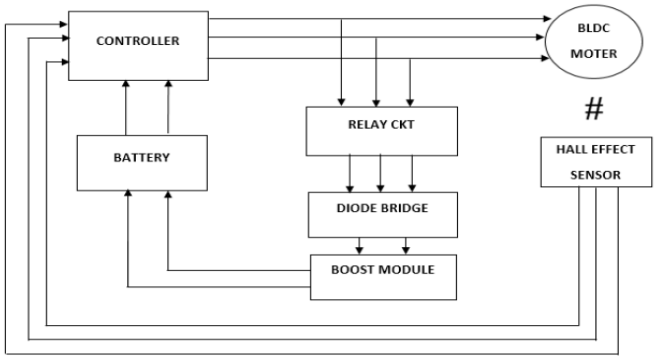

Fig 5:- Basic Connection Diagram

Arduino UNO controller is used to produce other control signals and switching signals. Boost module, which is a step-up chopper, gives required current and voltage so the battery can be charged efficiently.

➢ *Battery Selection*

Lithium ion batteries have high energy density, lower rate of self-discharge than that of other rechargeable cells such as Nickel Cadmium (Ni-Cad) and NiMH forms, and requires less maintenance. Hence Lithium ion batteries of 12 V, 7.2 Ah are used for supplying the required input power.

➢ *Practical Implementation*

Motor is attached to the carriage of bicycle using nut-bolts. Power generated in the motor is transmitted to rear wheel by chain drive. To counterweight the motor, one battery is placed on the other side. Another battery and control circuit is placed in the box on the carriage as shown in the figure below.

Fig 6:- Complete Bicycle Picture

V. CONCLUSION AND FUTURE SCOPE

When operated with full charged battery a distance 20-22 Km can be reached.

Advantages of hybrid cycle over conventional bicycles are:

➢ *Mobility*

People living in remote areas can cycle using a Hybrid cycle instead of depending on motorized transport alternative such as cars or motorbikes.

➢ *Effort*

Comparing with other options of non-fuel transportation, the same distances can be reached with less effort and within less time. When going uphill a rider on a Hybrid cycle will have to put less energy.

➢ *Higher range*

Since the rider will have to put less energy, and average speeds being higher, longer distances can be reached within less time.

Changes can be made in the mechanical design and arrangement to reduce weight such as designing complete bicycle frame of special strong plastic material. Wheel having spokes of greater strength should be used. Torque sensors can be used to detect the pedal torque and to make the bicycle pedal assist. Rear wheel hub motor can be used instead of chain drive arrangement as it becomes easy for mechanical arrangement.

REFERENCES

[1] Xiaohong Nian, Fei Peng, and Hang Zhang "Regenerative Braking System of Electric Vehicle Driven by Brushless DC Motor" IEEE Transactions on Industrial Electronics, VOL. 61, NO. 10, OCTOBER 2014

[2] Phaneendra Babu Bobba and K. R. Rajagopal, Senior Member, IEEE "Compact Regenerative Braking Scheme for a PM BLDC Motor Driven Electric Two-Wheeler"

[3] V. Sindhuja, G. Ranjitham, "Regenerative Braking System of Electric Vehicle Driven by BLDC Motor" IJIRSET Vol.3, Issue 12, December 2014

[4] "Fundamentals of Electrical Drives", Second Edition, by Gopal K. Dubey, Narosa Publishing House, New Delhi.

[5] "Hardware Design Considerations for an Electric Bicycle Using a BLDC Motor" by Texas Instruments

[6] C. H. Chen and M. Y. Cheng "Implementation of a Highly Reliable Hybrid Electric Scooter Drive", *IEEE Trans. on Industrial. Electronics*.,vol. 54, no. 5, pp.2462-2473, Oct. 2007

[7] B. Long, S.T. Lim, J.H. Ryu and K.T. Chong, "Energy-Regenerative Braking Control of Electric Vehicles Using Three-Phase Brushless Direct-Current Motors", in *Energies*, nr. 7, December 2013.