March 09, 2016

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, BC
V5A 1S6

Re: ENSC 305W/440W Design Specification for a New Designed Hybrid Bicycle

Dear Dr. Rawicz,

The enclosed document, Design Specification for a New Designed Hybrid Bicycle, outlines our project for ENSC 305W/440W, which intends to research and develop a new hybrid bicycle with several innovations on its driving system and some new features on its operating system.

This document provides the design specifications of our new dew designed hybrid bicycle, including the required components for BLDC Motor control system and regenerative braking control system. The design specification is related to the functional specification and will explain how each component works.

4E Technology consists of four talented, passionate Engineering students, Jason Li, Jim Zhang, Sheng Sheng and Coco Gong. Please feel free to contact me if you have any questions about our function specification. I will reply you as comprehensive as possible by email at yuanjiez@sfu.ca.

Best Regards,

Jim Zhang
COO of 4E Technology Inc.
Enclosure: *Design Specification for a New Designed Hybrid Bicycle*

Design Specification

For A New Designed Hybrid Bicycle

Project Team: Jason Li
Sheng Sheng
Jim Zhang
Coco Dong

Contact Person: Jim Zhang
yuanjiez@sfu.ca

Submitted to: Dr. Andrew Rawicz – ENSC 440
Steve Whitmore – ENSC 305

Issued Date: March 10, 2016

Revision: 1.1

Executive Summary

Tired of endless finding parking position? Impatient of traffic jam? Upset about the increasing price of gasoline? Due to these increasing number of social and environmental issues yielded by cars, more and more people prefer to consider one environmentally friendly and cost-effective way for daily trip, which is the bicycle. However, some selling reports show that the sales volume of bicycles for last few years is not as large as we expected. The main reason is that the number of uphill in the city area is pretty large, and the country roads are usually rugged, which increase the cycling difficulties. The emergence of electric bicycles have figure out some of the problems, but still cannot meet the needs of all due to the limitation of its battery. Our new designed hybrid bicycle is a perfect solution to the above questions with its energy-convertible driving system.

The most attractive of this bicycle is that its kinetic energy can be converted into electrical energy and stored in battery, vice versa. The stored electrical energy can be used as a power bank. When riders encounter uphill or bumpy roads, the stored electrical energy will be converted to kinetic energy automatically in order to enhance the mobility of bicycles, which will reduce the burden on riders' muscles.

In this design specification, we provide detailed description of the design and development of prototype. This document mainly demonstrates the details of the two control systems and driving system. Furthermore, all functional specifications have been strictly adhered to in order to ensure a quality product.

Overall, this document provides more detailed design specifications for BLDC Motor control system and regenerative braking control system, as well as other characteristics of the entire system.

Table of Contents

Executive Summary i
List of Figures and Tables ii
Glossary iii
1. Introduction 1
1.1. Scope1...1
1.2. Intended Audience..1
1.3 background...1
2. System Overview...2
3. Overall system design..3
3.1 Structure overview..4
4. Propulsion System Design..5
4.1 BLDC motor...5
4.2 Three phase explanation..6
4.3 MOSFET specification 8
4.4 Pulse with modulation design...10
4.5 Motor driver design...10
5.Generation System design...13
5.1 Generator driver design.. 13
5.1.1First stage of regenerative braking..13
5.1.2 stage 2 of regenerative braking 14
5.2 User interface of Regenerative braking..15
6. Periphery system design..16
6.1Pedal assist design..16
6.2 Battery percentage measurement and display..17
7. Conclusion..19
8. Reference...20
9. Appendix..23

List of Figures and Tables

Figures

Figure 1 High level system diagram..3
Figure 2 Structure Overview of the HEB 4
Figure 3 BLDC and hub Motor...5
Figure 4 Permanent Magnet BLDC Construction...6
Figure 5 Motoring Current Flow for a Commutation sequence............................7
Figure 6 IRFB3306PbF MOSFET...8
Figure 7 Pulse width Modulation signal processing..9
Figure 8 BLDCM Arduino control circuit..10
Figure 9 Circuit Construction...11
Figure 10 470uF Capacitor...12
Figure 11 Schematic diagram of circuit 12
Figure 12 Initial current flow while braking (step 1 of commutation)....................14
Figure 13 Regenerative braking current flow (step 1 of commutation)................15
Figure 14 Rotary potentiometer...15
Figure 15 Reed switch...16
Figure 16 Bicycle parts..16
Figure 17 Circuit design of battery percentage measurement............................18
Figure 18 LCD display board...18

Tables

Table 1 Forward Motoring Commutation Sequence...6
Table 2 Inverter switching sequence..7
Table 3 Basic spec of FB3306..10
Table 4 Regenerative Inverter Operation...13

Glossary

Hub motor	An electric motor that is incorporated into the hub of a wheel And drives it directly
HEB	Hybrid E-Bicycle
BLDCM	Brushless DC motor
Flyback diode	a diode used to eliminate flyback
SMPS	Switched-mode power supply
PM	permanent magnet

1. Introduction

With a wonderful energy conversion system, this new designed hybrid bicycle is a multi-functional bike, which is suitable for people of all ages. The design specifications for our hybrid bicycle are described and explained in document.

1.1 scope

The document describes the design specifications of our new designed hybrid bicycle, which will analyze technical aspects of two special control systems and will provide a detailed explanation for the decision of selected components to be used. Also, this design specification shows how we can achieve the functional specifications in detail.

1.2 Intended Audience

This design specification is implemented by all members of 4E technology Inc. Our team will refer to this document as overall design goals through development. This document will also be used to justify any design decision as well as serve as a template for future modification, if any issues are encountered during the testing and quality assurance stage before finalizing the product. Design engineers can refer this document to reflect on the requirements needed for regenerative braking system of HEB and make sure all requirements are met in the final product. Test engineers should use this guide to verify the functionality of the system.

1.3 Background

Due to environmental issues generated by motor vehicles, the bicycle has become a more popular means of transportation among workers and students. However, one statistics report of bicycle marketing shows a very slow increasing trend of the bicycles use, which is almost a flat trend. The hybrid bike is the only type of bike that purchasing trend keeps increasing. But its battery limitation will definitely affect the sales volume and this may not be very convenient to riders as well. Therefore, we came up with the idea of a hybrid bike with energy conversion system, which can perfectly solve all these problems. This new designed hybrid e-bicycle has an attractive feature where its kinetic energy can be converted into electrical energy and stored in battery and vice versa. The stored electrical energy can be used as a power bank to charge phone and support some devices during a long trip. When riders encounter bad road conditions, the stored electrical energy will be converted to kinetic energy automatically to enhance the mobility of bicycles.

2. System Overview

The HEB functions as both exercise bike and commuter bike in human's daily life. in order to make it a multi-purpose bicycle, there are two main systems which are propulsion system and power regeneration system.

In the HEB, the propulsion system is consisted of pedals, sprockets, crank, chain, freewheel, rear axle, rear-wheel, hub motor and lead-acid batteries. Customers shall rotate the pedals to provide a human power which goes through cranks, sprockets, chain, freewheel, rear axle and eventually delivers the power to rear wheel. In addition, the BLDCM provides driving force to rear-wheel to assist propelling the bike.

In the HEB, power regeneration system shares the components with propulsion system. When the HEB is cycling or sliding, users could brake the HEB to create back EMF in the motor armature winding. When the voltage of winding is greater than the battery with the control of MOSFET switches, current will flow back to the batteries thus charging the batteries.

The system that can be modeled as a high level block diagram shown below.

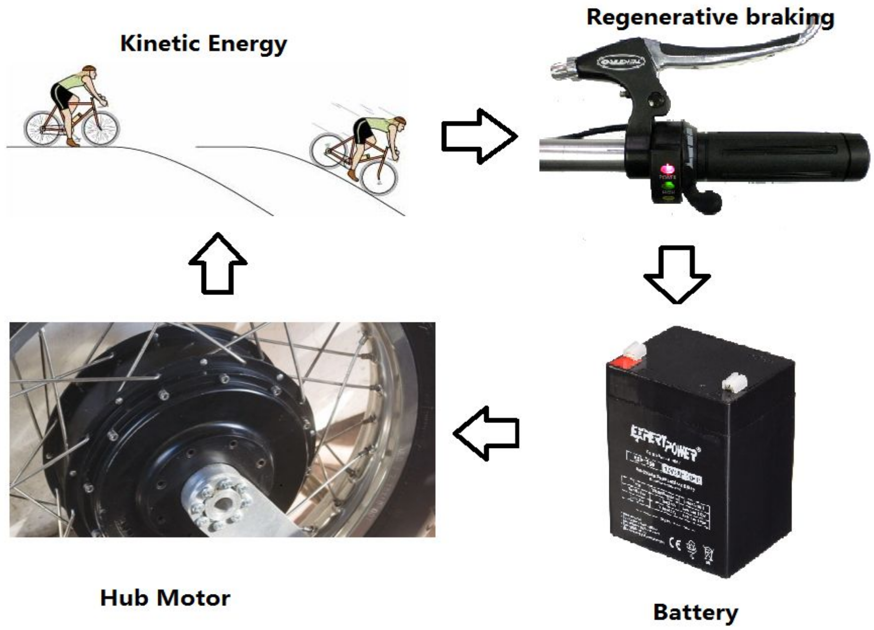


Figure 1. High level system diagram [2] [5] [6] [7]

Batteries are providing electric power to the BLDCM, which converts electric energy to Kinetic energy. A small portion of kinetic energy or the potential energy of the HEB can be further transformed back to the electric energy stored into the batteries.

3. Overall system design

The propulsion and power regeneration of bike are achieved by corresponding input. In throttle mode, the propulsion of bike could be controlled by rotation of the throttle. In the pedal assist mode, the bike could be propelled by BLDC motor when pedaling. Power regeneration can be achieved by braking while braking and sliding.

3.1 Structure overview

Figure 2, Structure Overview of the HEB [5] [6] [8] [9] [10] [13] [14] [15]

This figure illustrates the general structure of the HEB. We place the hub motor to the front wheel to avoid compatibility problem that may arise if placed at rear wheel. The controller and the batteries will be placed under the beam of HEB to ensure better weight distribution of user and HEB as a whole. User's weight is mainly distributed on the rear wheel. As we are building a front wheel drive electric motor, more weights should be placed to the front wheel to avoid skidding while motoring.

4. Propulsion System Design

4.1 BLDC motor

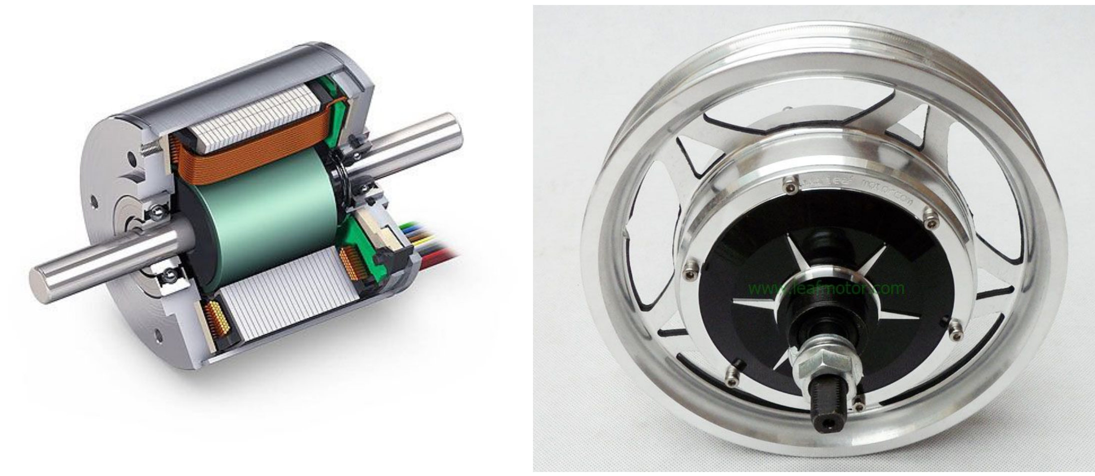


Figure 3, BLDC and hub Motor [1] [2]

A BLDC motors tend to be more reliable, last longer, and be more efficient than brushed DC motor. In fact, BLDC motors have life expectancy of over 10,000 hours[3]. BLDC motor is the most commonly used motor in electric bicycles and hybrid cars. Therefore, we choose BLDC as our motor as well as generator.
The BLDC motor we are using for HEB is a hub motor which is Incorporated into the wheel of motor as shown in figure 3.

4.2 Three phase explanation

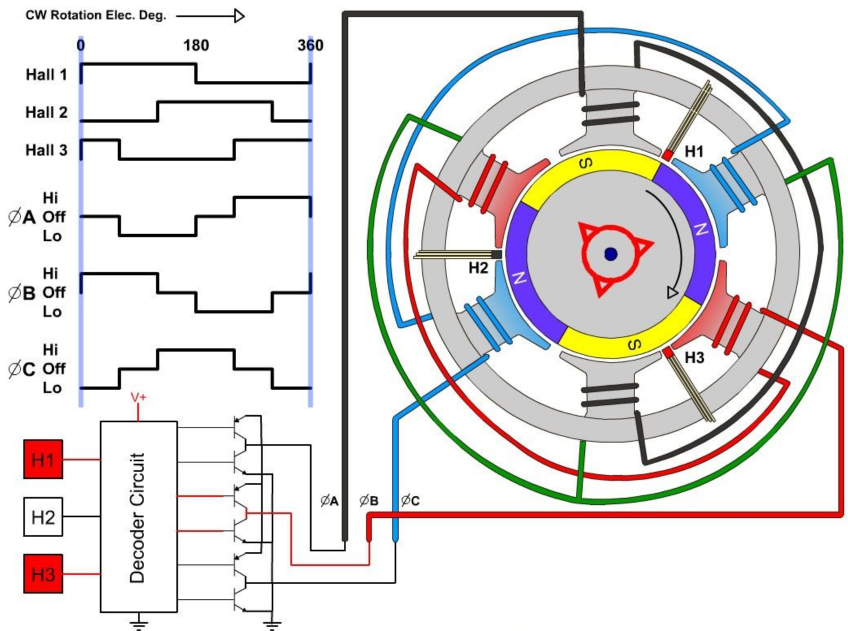


Figure 4. Permanent Magnet BLDC Construction[4]

Permanent Magnet BLDC consists of 3 phase armature coil, permanent magnet rotor and 3 hall effect sensor.During motoring process, 2 out of 3 phases will be excited at the same time. one phase will form a north pole on one end of the armature coil and a south pole on the opposite end, which will either pull/push the permanent magnet of rotor. The other excited phase will form similar poles on 2 ends of the armature coil which will either push/pull the permanent magnet of rotor. The torque provided by the armature to the rotor will enable the wheel rotating clockwise.

Along with the rotation of the rotor, the excitation phases will be changing to ensure continuous torque to the rotor; therefore, one revolution of the rotor is divided into 6 steps to complete. The Hall effect sensors, which are placed at the rotating track of the rotor, are to locating the position of the rotor. The commutating sequence or the sequence of excitation phases is shown in table 1.

Table 1, Forward Motoring Commutation Sequence

Step	Hall A	Hall B	Hall C	Phase A	Phase B	Phase C
1	1	0	0	-V	+V	NC
2	1	0	1	NC	+V	-V
3	0	0	1	+V	NC	-V
4	0	1	1	+V	-V	NC
5	0	1	0	NC	-V	+V
6	1	1	0	-V	NC	+V

Table 2 shows the corresponding MOSFET switches sequence in a complete cycle with respect to Table 1.

Table 2, Inverter switching sequence

Step	On Switches	Remaining Switches
1	B_High A_Low	Off
2	B_High C_Low	Off
3	A_High C_Low	Off
4	A_High B_Low	Off
5	C_High B_Low	Off
6	C_High A_Low	Off

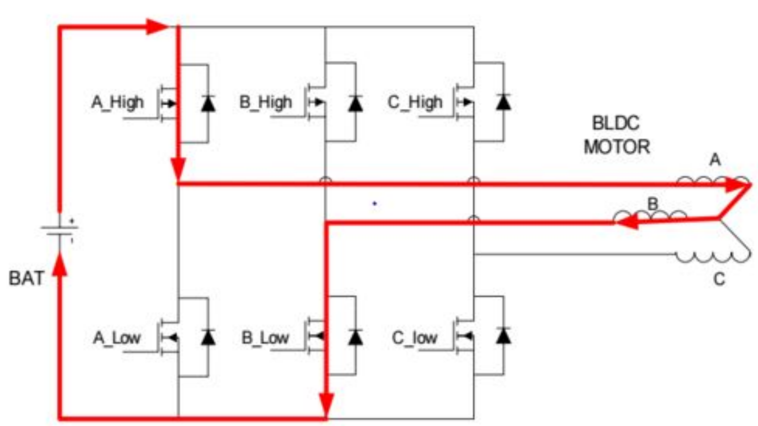


Figure 5. Motoring Current Flow for a Commutation sequence[16].

The figure demonstrates the fourth commutating sequence of the BLDC as shown in the Table 2. at this stage, A_high switch and B_low switch are turned on. We choose to use MOSFET since it can withstand high power load[16]. The max possible current of the circuit is 10A which is the amount of current that going from the sources to the drains or the other way around.

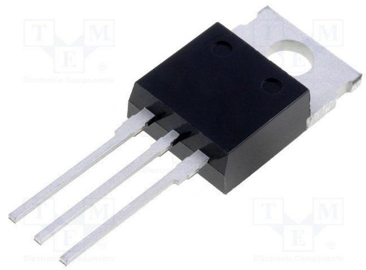


Figure 6. IRFB3306PbF MOSFET[17]

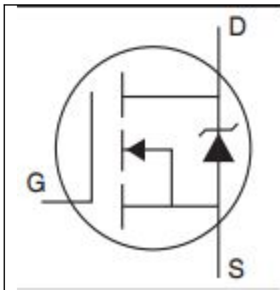
4.3 MOSFET specification

In M/G driver circuit, we used MOSFET as transistors. In order to achieve high efficient operation for propulsion system and power regeneration system in HEB, the transistors in the M/G driver circuit must meet the following requirements.

- High Speed Power Switching
- Uninterruptible Power Supply
- High Efficiency Active rectification in SMPS
- Hard Switched and High Frequency Circuits

The Rectifier with model FB3306 can match all this requirements [ref]. The current will flow across the MOSFET when the batteries supply the power. however, the current will flow across the diodes when the BLDC motor supplies the power to charge the batteries. The MOSFET Symbol and basic specification are shown in Table 3:

Table3. Basic spec of FB3306 [1]

	V_{DSS}		60V
	$R_{DS(on)}$	Typ.	3.3 mΩ
		Max.	4.2 mΩ
	I_{D} (Silicon Limited)		160A
	I_{D} (Package Limited)		120A

Six diodes are in parallel with each MOSFET. These diodes are called flyback diodes since they are used to eliminate flyback which is a sudden voltage spike. it happens when the switching between the commutating sequence. the Armature coil considered as an inductor, the extreme large negative potential is created by the inductor when experiencing sudden drop of current . the large potential difference will cause the spike across the air gap of the MOSFET and may permanently damage the MOSFET.

4.4 Pulse with modulation design

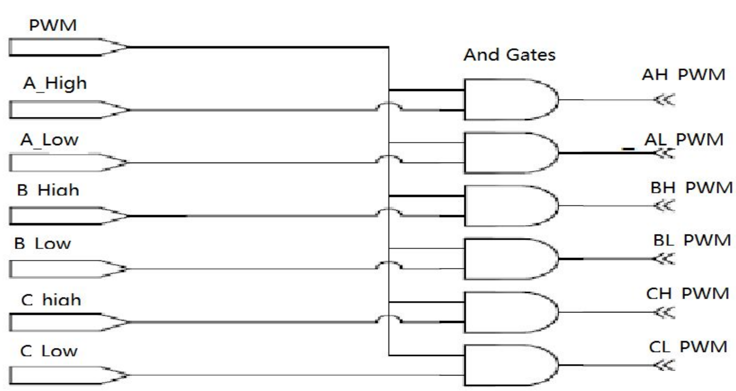


Figure 7. Pulse width Modulation signal processing.

A_high, A_low, B_high, B_low, C_high and C_low are current outputs to the gates of MOSFETs, thus functioning as switches. When the current flow to the gate of MOSFETs, the MOSFETs will be turned on. Before the currents go to the gates of the MOSFETs, they are modulated by PWM analog signal. The AH_PWM, AL_PWM, BA_PWM, BL_PWM, CH_PWM and CL_PWM are the pulse width modulated signals. the currents going through the MOSFETS are controlled by these pulse width modulated signals, thus changing the currents in the three phase motor windings and torque provided.

4.5 Motor driver design

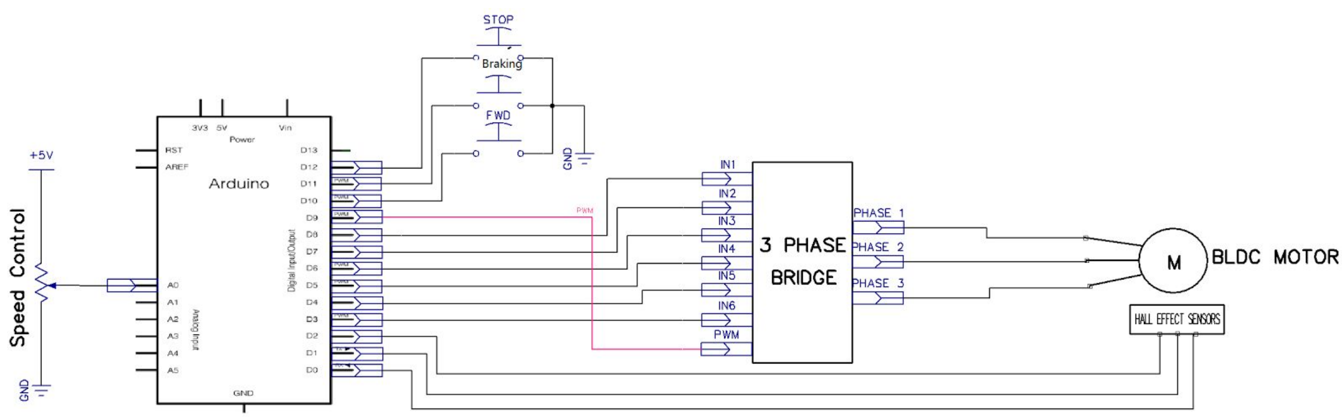


Figure 8, BLDCM Arduino control circuit.

The figure 8 illustrates the motoring control of BLDC by Arduino Uno.
Some changes will be made to the design circuit due to regenerative braking system. We tried to simulate the motoring and regenerative braking system with Fritzing software.

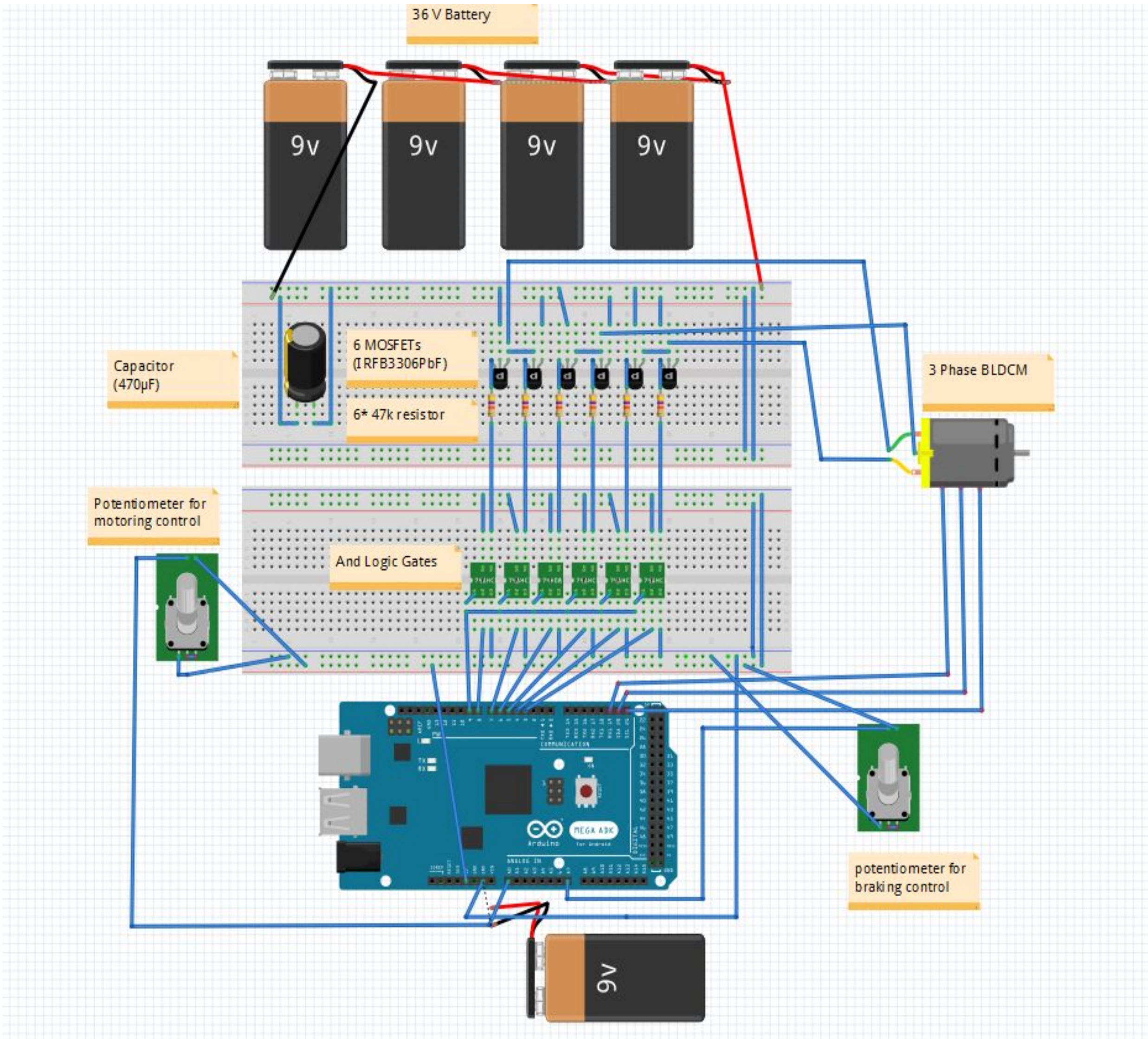


Figure 9 Circuit Construction

We add 1 large capacitor with high capacitance in parallel with the batteries. 2 reasons for adding an capacitor:

1. It performs better at supplying high current in the first few milliseconds than the batteries do.
2. It prevents motor from resisting the rotation of rotor while MOSFET switches by absorbing some of the energy that comes out of the motor, and ensure the digital electronics and motor continue to operate normally. The capacitors will dissipate that energy back to the motor when the switch turns on.

Figure 10. 470uF Capacitor [12]

We show the construction of the circuit with respect to the figure 11. The motor we used in the diagram is not the real component we are using because we can't find BLDC motor we used in this software.

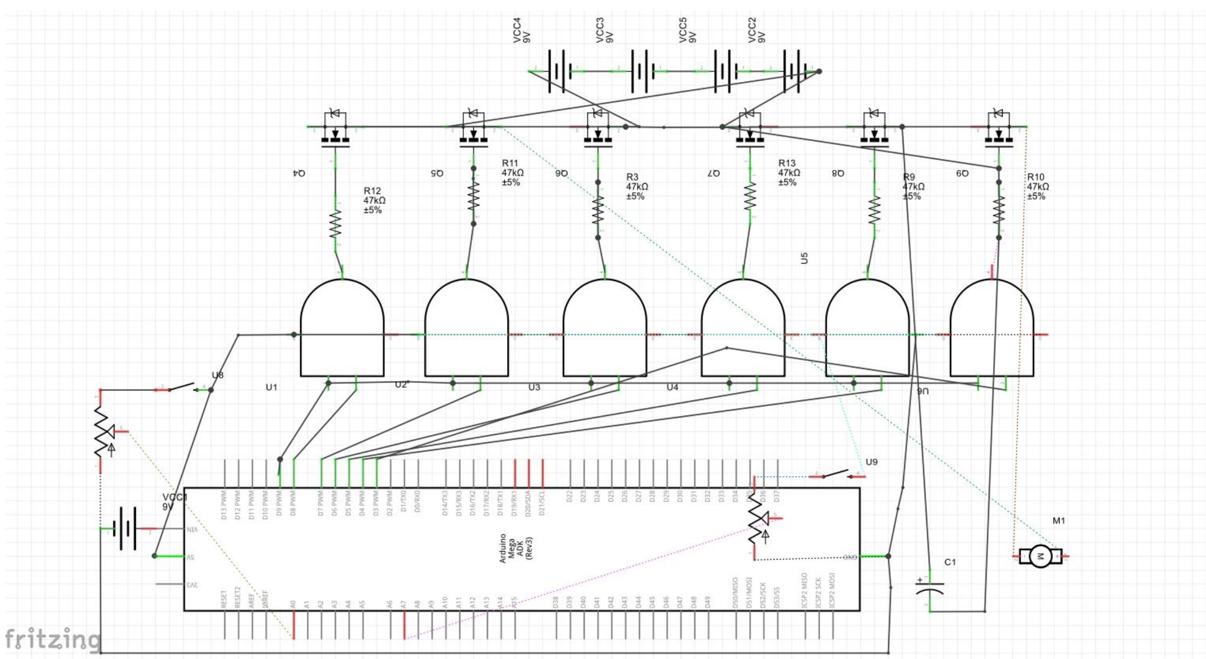


Figure 11. Schematic diagram of circuit

5 .Generation System design

The decided to use the BLDC motor in propelling system to function as a generator. Thus, BLDC motor works as motor and generator which is different from the initial design from our proposal. We choose the BLDC motor for our regenerative system for several reasons:

1. BLDC motor has permanent magnet on the rotor; turning the rotor in the stator coil will induce 3 phase AC output. After converting AC to DC output by converter, battery charging begin.
2. If we have an alternator and a BLDC motor as our regenerative and propelling system respectively, the hybrid e-bicycle will be 3 kg heavier which leads to less cruise range and unpleasant cycling experience.
3. The cost of bike will increase about 20% to 30% as buy another generator for power regeneration.
4. The potential market of a heavier and more expensive bike will not be as competitive as the bike with one M/G.

5.1 Generator driver design

Generator driver is used to control charging batteries when HEB is braking. The circuit of generator driver is same as the circuit of motor driver. However, in order to ensure the current could flow back into batteries and charge batteries, controlling the transistors in the circuit is the most important. The Hall Effect sensor in the motor will send signal to PWM in Arduino and PWM will control the transistors.

5.1.1 First stage of regenerative braking

The table 4 shows the PWM switch sequence at the beginning of braking.

Table 4 Regenerative Inverter Operation

step	PWM Switch	OFF Switch
1	A_low	Remaining
2	C_low	Remaining
3	C_low	Remaining
4	B_low	Remaining
5	B_low	Remaining
6	A_low	Remaining

The corresponding current flow in the circuit is shown in figure 12. In this mode, the energized windings allow the current to flow through the low-side of the PWM switch and through the freewheeling diode of the low-side high phase switch. Thus no current flows from the BLDC machine to the supply battery.

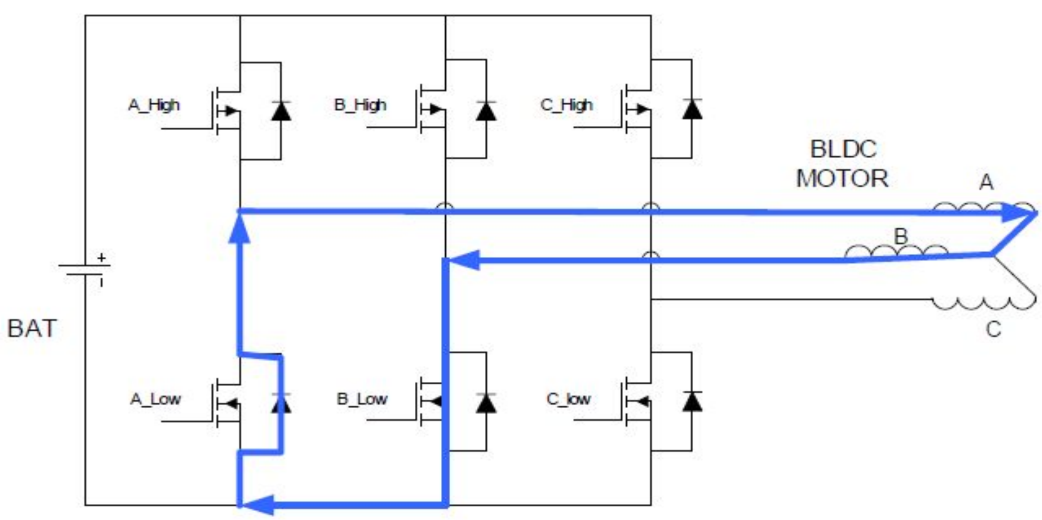


Figure 12. Initial current flow while braking (step 1 of commutation)[16]

5.1.2 stage 2 of regenerative braking

In this mode, all switches are turned off and the current can flow back through the freewheeling diodes.The charging begins at this stage.

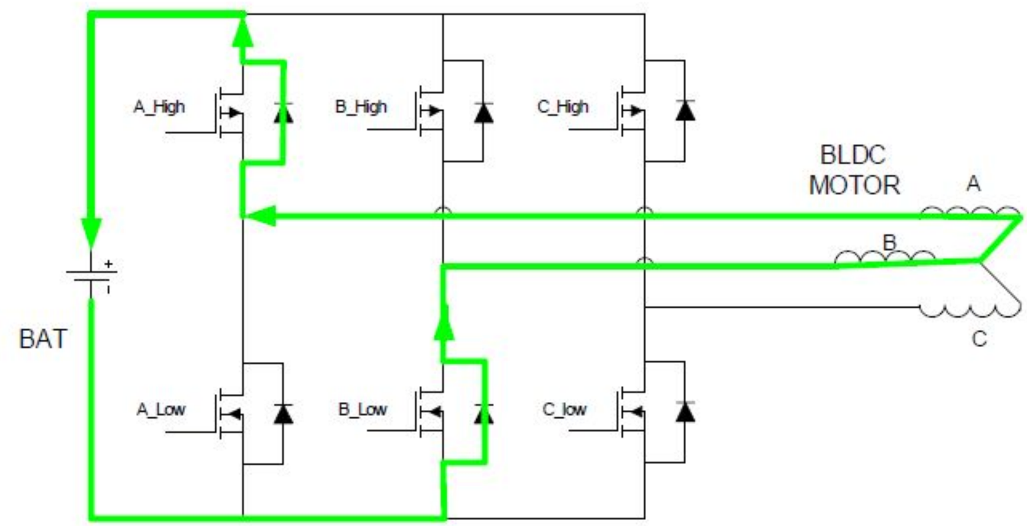


Figure 13. Regenerative braking current flow (step 1 of commutation)[16]

5.2 User interface of Regenerative braking

A rotary potentiometer is used to control the degree of braking in our regenerative system as shown in figure 14. The current flows from the potentiometer to the analog input port of Arduino. The higher the current flowing into the port the higher the duty cycle of PWM signal thus higher the degree of braking. The magnitude of current is adjusted by the rotation of potentiometer.

Figure 14. Rotary potentiometer [10]

6.Periphery system design

6.1 Pedal assist design

Pedal assist mode is to facilitate users while cycling. The HEB will start motoring automatically when user is pedaling clockwise. This function will be achieved by reed switch and permanent magnet. The PM is placed on the crankarm of HEB and 3 reed switches are placed at seat tube, down tube and chainstays respectively as shown in figure 15 &16.

Figure 15. Reed switch[15]

Figure 16. Bicycle parts[8]

When the crankarm with the permanent magnet reach the position of reed switch, the switch will be turned on and received by arduino digital input port. According to the signal sequence and the time interval of reed switches, Arduino could calculate the speed the direction of crankarm rotation.

6.2 Battery percentage measurement and display

Arduino's analog inputs can be used to measure DC voltage between 0 and 5V . and this range can be increased by using two resistors to create a voltage divider. The voltage divider decreases the voltage being measured to within the range of the Arduino analog inputs. An algorithm in the Arduino is used to compute the actual voltage being measured.

The analog input port on the Arduino board can read the voltage on the analog pin and converts it into a digital format that can be processed by the micro-controller. Input voltage are feed to the analog pin (A 3) using a simple voltage divider circuit comprising resistors R1 (100K) and R2 (10K). With the values used in the voltage divider into the Arduino board. The junction on the voltage divider network connected to the the Arduino analog pin is equivalent to the input voltage divided by 11; therefore;The possible feed voltage range is from 0V to 55V. Hence, when measuring 55V, the Arduino analog pin will be at its maximum voltage of 5V. The circuit shown in figure 17 explains the method of voltage measurement.

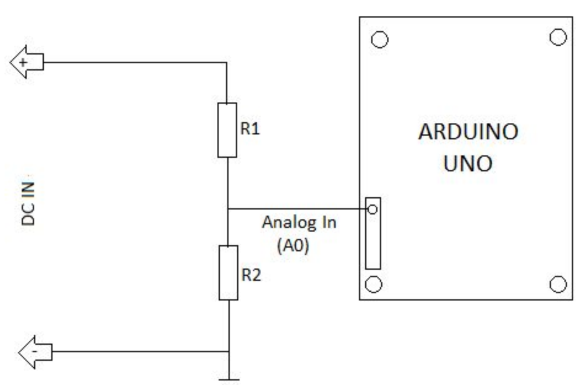


Figure 17. Circuit design of battery percentage measurement.

A LCD will be used to display the calculated battery percentage. The LCD will be placed on the handle bar of the HEB.

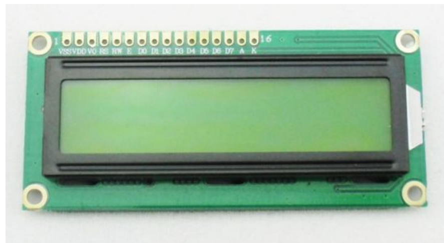


Figure 18. LCD display board[11]

7.Conclusion

The design specification clearly shows how we intend to meet our functional requirements of our new designed hybrid bicycle. We have included details of the electronic and mechanical design of two main control systems. Some other important components are also described in this design specification.

The prototype of our new designed hybrid bicycle will be based on all requirements mentioned in functional specification, which is expected to be completed with a high quality by April 4th.

8.Reference

[1] BLDC motor
Available: http://www.designworldonline.com/highly-dynamic-brushless-dc-motors/[2012]

[2] Hub motor
Available: http://www.homepower.com/articles/vehicles/project-profiles/electric-motorcycle-diy-primer[2012]

[3] Advantages of BLDC
Available: http://www.nmbtc.com/brushless-dc-motors/why-brushless-motors/ [2011]

[4] BLDC construction
Available: http://www.avdweb.nl/solar-bike/hub-motor/permanent-magnet-dc-hub-motor-tuning.html [2012]

[5] ExpertPower EXP1250 12V 5Ah Home Alarm Battery with F1 Terminals
Available:http://www.amazon.com/gp/product/B0010Z4MDK?keywords=12v%20lead%20acid%20battery&qid=1457599672&ref_=sr_1_2&sr=8-2 [2016]

[6] Throttle
Available: http://us.itselectric.ca/category_s/54.htm [2016]

[7] The Nature of Energy
Available:
http://wps.prenhall.com/wps/media/objects/3311/3390593/blb0501.html [2011]

[8] Bicycle
Available: http://www.bikesdirect.com/products/dawes/lt_sport_al_xiii.htm [2016]

[9] Hub motor installed into wheel
Available: http://www.leafmotor.com/hub-motors/12inch-electric-scooter-motor.html [2016]

[10] Rotary potentiometer
Available: https://www.kitronik.co.uk/c3002-10k-panel-mount-10k-pot.html [2016]

[11] LCD display
Available:http://www.elecrow.com/wiki/index.php?title=File:16x2_Character_LCD_Display_Module_-_Yello1_01.jpg [2016]

[12] Capacitor
Available: http://www.ebay.com/itm/20-x-470-F-470uF-16V-105-RM3-5-Elko-Kondensator-Capacitor-Samwha-E-Cap-20pcs-/161421050413 [2016]

[13]Controller
Available: http://www.ebay.com/bhp/36v-scooter-controller[2016]

[14] Permanent magnet
Available: http://www.everychina.com/m-permanent-magnets-for-sale[2016]

[15] reed switch
Available: http://www.ebay.com/itm/5x-Magnetic-RFT-Germany-REED-Switches-36W-50mm-glass-SPST-Normally-Open-Gold-/351087282472?hash=item51be6ec928:g:nU8AAMXQTT9Ro1fN[2016]

[16] REGENERATIVE BRAKING IN AN ELECTRIC VEHICLE
Available: http://www.komel.katowice.pl/ZRODLA/FULL/81/ref_20.pdf[2009]

[17] Datasheet – International Rectifier, “IRFB3306PbF, IRFS3306PbF, IRFSL3306PbF”
Available:http://www.irf.com/product-info/datasheets/data/irfs3306pbf.pdf .[2016]

Appendix

Test Plan:

This following test plan is used to ensure whether the final product meets the functional specifications' requirements. The multiple tests will be covered all high-level product mechanism and system performances in different kinds of condition.

1. Propulsion Test Plans

1.1 Pedal Assist sub-mode

Test Unit	Test Procedure	Expectation
Propulsion By motor	Pedaling	The motor automatically turns on at maximum load
Propulsion By pedaling	Pedaling	Smooth riding experience
Throttle Control	Rotating the Throttle	No response from motor

1.2 Throttle Control sub-mode

Test Unit	Test Procedure	Expectation
Throttle Control	More rotation of throttle	More power will be delivered to the wheel
Pedal only	Pedaling	No response from motor

1.3 Human Power sub-mode

Test Unit	Test Procedure	Expectation
Propulsion By pedaling	Pedaling	No response from motor
Throttle Control	Rotating the Throttle	No response from motor

2. Generator Test Plans

Test Unit	Test Procedure	Expectation
Regeneration Braking	Rotating the rotary potentiometer	Braking applies and batteries are charging

3. Control System Test Plans

Test Unit	Test Procedure	Expectation
Battery percentage Display	Turn on display board	LCD shows proper battery percentage
Speed Display	Riding HEB	LCD shows proper riding speed
Mode changing while riding	Changing the bicycle mode by pressing the mode switch	The bicycle mode can be changed properly

4. Durability Test Plan

Test Unit	Test Procedure	Expectation
Waterproof	Riding in raining day	Every single function of HEB are working properly
Ability to withstand Terrain interference	Riding in various road conditions	Every single function of HEB are working properly
Ability to withstand high Temperature	Long-term riding in high temperature	Every single function of HEB are working properly