Automotive Regenerative System

By
Ali Zahid Khan
Fahad Ahsan
Muhammad Ausama Raees

Supervised By

Dr. Mohsin Jamil

School of Mechanical and Manufacturing Engineering,

National University of Sciences and Technology (NUST),

Islamabad, Pakistan

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Ali Zahid Khan	**NUST201200609BSMME11112F**
Fahad Ahsan	**NUST201200933BSMME11112F**
Muhammad Ausama Raees	**NUST201200960BSMME11112F**

Supervised By

Dr. Mohsin Jamil

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FINAL YEAR PROJECT REPORT

We hereby recommend that the dissertation prepared under our supervision by: Ali Zahid Khan NUST201200609BSMME11112F, Fahad Ahsan NUST201200933BSMME11112F , Muhammad Ausama Raees NUST201200960BSMME11112F Titled: Automotive Regenerative System be accepted in partial fulfillment of the requirements for the award of Bachelors of Engineering in Mechanical Engineering degree with (_____ grade)

English and format checked by Ms Aamna Hassan, Signature:_________________

Guidance Committee Members

1. Name: Dr. Samiur Rahman Shah Signature:_________________

2. Name: Dr. Omer Gillani Signature:_________________

3. Name: ______________________________ Signature:_________________

Supervisor's Name: Dr. Mohsin Jamil Signature:_________________

Date:__________________

____
Head of Department

____
Date

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____
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Signature of Student
Ali Zahid Khan
NUST201200609BSMME11112F

Signature of Student
Fahad Ahsan
NUST201200609BSMME11112F

Signature of Student
Muhammad Ausama Raees
NUST201200609BSMME11112F

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Dedicated to our parents

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Abstract

Our objective was the design and manufacture of a Hybrid motorbike conversion kit with regenerative braking to show that regenerative braking can increase the range of a motorbike in an urban setting and increase its efficiency. We developed a prototype to demonstrate the waste energy recovery through regenerative braking. This prototype will also serve as a starting point for future students to optimize regenerative braking systems. The resultant energy regeneration and recovery at the end of testing was significant and can be the next step in the automotive industry working towards a more green future.

Table of Contents

List of Symbols

Symbol	**Description (unit)**
F	Force (N)
m	Mass (kg)
a	Acceleration (m/s2)
A	Area (m2)
Cd	Coefficient of Drag (unit less)
ρ	Density (kg/m3)
v	Velocity (m/s)
g	Gradational Acceleration (m/s2)
Cr	Coefficient of Rolling Resistance (unit less)
P	Power (W)
E	Energy (J)
I	Current (A)
f	Frequency (Hz)
C	Capacitor (F)
R	Resistor (Ω)
V	Voltage (V)
I	Current (A)

Chapter 1

Introduction

1.1 Background

Loss of power and efficiency in electrical and mechanical systems has been a constant problem in automotive design. In recent years, energy regeneration has made rapid advances in the automotive world. Regenerative braking is defined by the United States Department of Energy as a system that captures the energy lost during braking by utilizing an electric motor as a generator and storing the energy captured. This extra energy is re-used during acceleration, providing the vehicle with more energy and a longer range. Energy regeneration is not only a concept that has been applied to automobiles, but is also an application which has been applied on a smaller scale to motorcycles, motorbikes and scooters.

There is an ever increasing need for more sustainable ways in which we use energy. While regenerative energy is relatively new and expensive technology; it can be a small yet significant step towards a more sustainable and ecofriendly vehicle.

Regenerative braking is not a new concept. There is much room for improvement in the technology, especially in its design and in making it portable instead of only being limited to specially manufactured vehicles.

1.2 Executive summary:

This project was geared towards making already existing motor bikes into more economical hybrid bikes without high overhead costs. Therefore we designed and manufactured conversion kit which could be attached to any 70 cc motorbike and make it an electro-mechanical hybrid with regenerative braking. We showed that regenerative braking can increase the range of a motorbike in an urban setting and improve its efficiency. Our prototype was used to demonstrate the waste energy recovery through regenerative braking and storing it into battery to power the the vehicle electrically later. This prototype will also serve as a starting point for future students to optimize regenerative braking systems.

The project began by analyzing state of the art hybrid vehicles, both motorbikes and cars, especially those with regeneration systems. There are a number of products in this market, but there are no products which can convert already existing vehicles into hybrids. Several simulations and calculations were performed to validate energy availability for regenerative braking. Based on this validation, 17% of the energy used in a typical urban driving cycle is potentially recoverable. This potentially recoverable energy does not consider drivetrain or electrical losses. Thus, the ultimate goal of this platform is to achieve as much energy recapture as possible.

In the pursuit of designing the most efficient system, the team took advantage of the most advanced mechanical and electrical design methods available. For designing, simulating and analyzing electrical circuits, we primarily used Proteus ISIS. For design and simulation of physical systems and the powertrain we utilized SolidWorks and we used Excel and Matlab for all theoretical calculations necessary for making a hybrid bike electric motorbike.

This project is not purely mechanical in nature; rather there were several aspects of mechanical and electrical design that synergized with each other to create this motorbike. The drivetrain required intensive stress and power analyses that allowed us to design and optimize the control and throttling circuits. In addition to that, considerations, such as component placement and weight distributions determined the physical design of the motorbike

Once design criteria were established, it was time to select components to meet specifications. Our focus was on using as many off market parts as possible, therefore the design was altered in according to specifications of components available to us. As components were reviewed, the design of the motorbike shifted in accordance with tangible specifications commercially available to the team. The main components that were finalized during this period consisted of the motor, the batteries, the transformer, and the donor bike frame. Additional minor components such as gears and circuit components were also selected based on the requirements of the main components.

The final design of this project can be divided into two major parts: mechanical and electrical. The mechanical design covered designing mountings for the motor and the generator, a drivetrain to transfer power from motor to the rear wheel, powertrain to run the generator, a casing to house electric components and controllers and a casing to hold the battery. The electrical design consisted of a unidirectional motor drive circuit, a regenerative braking circuit, a circuit to control the switching between mechanical and electronic drive, a mode selection circuit and a duty cycle modulation circuit. The motor drive circuit will allow the motor to be powered from the battery, while the regenerative circuit will allow for conversion of braking energy to chemical energy stored inside the battery. The mode selection circuit switched between drive mode and regenerative braking mode. The duty modulation mode lets the user control the speed of the bike. These electrical and mechanical systems work together in accord to produce a smooth functioning hybrid bike.

Once the final design was completed, fabrication began. Raw materials were obtained and machined into nonstandard components, while purchased components were modified and fitted. Various machining equipment such as mills and lathes were used by us in MRC machine shops as well as outsourced to various technicians to fabricate and modify components as necessary. Effort was made, both when designing and when fabricating, that minimal alterations be made to standard components. At times machining errors led to components being rendered useless and fabrication process had to be repeated. Electrical fabrication entailed the construction of PCBs and in addition to it, a myriad of other circuits.

After finishing the fabrication several tests on the motorbike were made. The motor was able to power the bike to the desired speed of 40kmph on flat surfaces; however torque was not sufficient to tart the bike from complete stand-still. At higher speeds (>40kmph) regenerative braking was tested and significant potential difference and current were recovered from the generator.

This was a very challenging FYP, and the team handled all difficulties and problems with a very pragmatic approach to complete the project deliverables. There were numerous facets that determined success in this FYP, and overcoming those obstacles developed our understanding of the practical and deeply varied challenges inherent to this type of engineering project. This motorbike is the next step towards ongoing efforts to find sustainable solutions and to minimize wasted energy in motorbikes for urban use. It is a first of its kind design and it will provide a platform for future projects to continue researching and developing a more proficient regeneration system, a lighter frame, and reduction of overall cost. Prospective students and staff interested in researching and developing methods to more effectively recover this energy should take note of this project and the progress made to establish a workable test bed for future study.

1.3 Current State of Technology

As regenerative vehicle exist, there is also an existing information available to us to work on. Most regenerative motorbikes have a significant energy return of 5-20%. On average, the distance added is about 10% further per charge. In this modern age, they are also becoming more user-friendly, with visual LCD's and charge monitors to create a more simple experience for the operator\ Finally, they are designed to be lightweight and utilize lighter lithium type batteries, but have powerful motors.

However one drawback of this technology is that one needs to build an entirely new vehicle to add regenerative braking into it. Currently, there is no way to equip older, preexisting vehicles on road with regenerative braking on a commercial scale. Through the initial research of the project group, the following specifications were researched and shown as a result of average values and feasible results.3

The current state of the art in terms of electrical systems involve some Lithium-ion type battery network, a motor capable of running on voltage levels varying from 36 volts to 100+ volts at ~30A current, boost networks to force the voltage levels of the motor higher than the battery supplied voltage so that current can flow back into the battery, and components utilized in the driving and recharge circuits that prevent back EMF from going back through the driving circuits and speed controllers and potentially exceeding ratings of components thus damaging vital systems. The speed controllers and driving circuits are highly optimized to maximize energy return from the regeneration systems and minimize power consumption from battery to motor during the drive cycle. However, none of these designs are suitable for use with common off market components and cannot be added to preexisting vehicles to improve their performance. Therefore a deviation from current technology was necessary to make a conversion kit more feasible both in terms of economics as well as manufacturing and installation.

1.4 Project Validation

To assess whether regenerative braking in motorbikes is a project worth pursuing, a method was developed to simulate the potential energy return from standard urban driving. The metric used to assess the efficiency of the motorbike during normal urban operation is called the ECE-15 Urban Driving Cycle (UDC which is part of the New European Driving Cycle (NEDC), and is supposed to be representative of a typical urban use pattern for a vehicle. Although this does not represent the driving conditions in Pakistan with extreme accuracy, it does give a very good approximation of driving situations of a typical vehicle in Pakistan.

Text of the UDC has been mentioned below:

When the engine starts, the vehicle pauses for 11 seconds (s), then slowly accelerates to 15 km/h in 4 s, cruises at constant speed for 8 s, brakes to a full stop in 5 s, then stops for 21 s.

At 49 s, the vehicle slowly accelerates to 32 km/h in 12 s, cruises for 24 s, slowly brakes to a full stop in 11 s, then pauses for another 21.

At 117 s, the car slowly accelerates to 50 km/h in 26 s, cruises for 12 s, decelerates to 35 km/h in 8 s, cruises for another 13 s, brakes to a full stop in 12 s, then pauses for 7.

The cycle ends on 195 s after a theoretical distance of 1017 meters, then it repeats four consecutive times. Total duration is 780 s (13 minutes) over a theoretical distance of 4067 meters, with an average speed of 18.77 km/h. [1]

These speeds described in this UDC are used in the energy simulation to define the speed of the simulated motorbike at different points in time. For example, between t = 11 and t =15, the speed of the simulated motorbike is defined as V = 1.04167*t-11.4583. The assumptions made ere are that the acceleration remains approximately constant between defined intervals. This will yield the correct value of speed and acceleration (in m/s, for ease of calculation) for theoretical calculations for the motorbike at that time in the cycle.

Once speed and acceleration are established, the force required to move the motorbike can be estimated based on speculative physical values for the bike. The origin of these values, and of the equations for validation, will be explained in more precise detail in the Power Requirements subheading of the Design Criteria section of project.

Two equations are used to estimate the force required to move the simulated motorbike. Using Newton's Second Law of Motion, we can calculate the force required to produce the necessary acceleration in the bike (in absence of any frictional losses). Since

$$\mathbf{F=ma}$$

We can find required force for constant acceleration of a fixed mass (bike).Since braking action is simply negative acceleration; this equation tells us that regenerative braking is possible.

In ideal cases the above equation alone will be enough for all simulations; however, in reality there are frictional losses and drag forces to be considered. Therefore a second equation will be used to find a summation of all frictional forces on bike during driving.

The equation is as follows:

$$F=1/2(A)(C.d)(v^2)(p) + mgu$$

There are two parts of the above equation. The first part is used to estimate the result of air resistance (drag) on the bike. It should be noted that drag forces increase with the square of velocity, and exponential increase. The second part of equation calculates the rolling drag on the bike from contact between the tyres and the road. Since mass of bike, gravity and coefficient of kinetic friction remain approximately same during entire drive cycle, this part of equation can be considered constant.

By combining both these equations we get the following results for net force on bike

$$F=1/2(A)(C.d)(v^2)(p) + mgu+ma$$

And we know that Power is a product of Force and Velocity

$$P=F*V$$

$$P=(1/2(A)(C.d)(v^2)(p) + mgu+ma)V$$

The above equation will be used to calculate the power requirements of the bike (and by extension, the motor) at different velocities. Since ECE-15 UDC describes velocity as a function of time during different intervals, we can get functions relating Time and Power after we substitute the values of velocity by corresponding equations in terms of time.

The bike shows three kinds of behavior during the drive cycle such as:

1. Acceleration: The bike shows an increase in speed and all the parts of the equation positively contribute to the motor's power requirement
2. Coasting: Acceleration becomes zero and F=ma part also becomes zero
3. Braking: F=ma part becomes negative as acceleration becomes negative.

The last point has an implication that if the braking is sufficient (F=ma part is negative and suitably large) we can overcome the power costs and have regenerative braking.

Using Matlab, we formed a graph (shown below) which demonstrates the relationship between the speed of the simulated motorbike and the power requirement of the motorbike over the UDC.

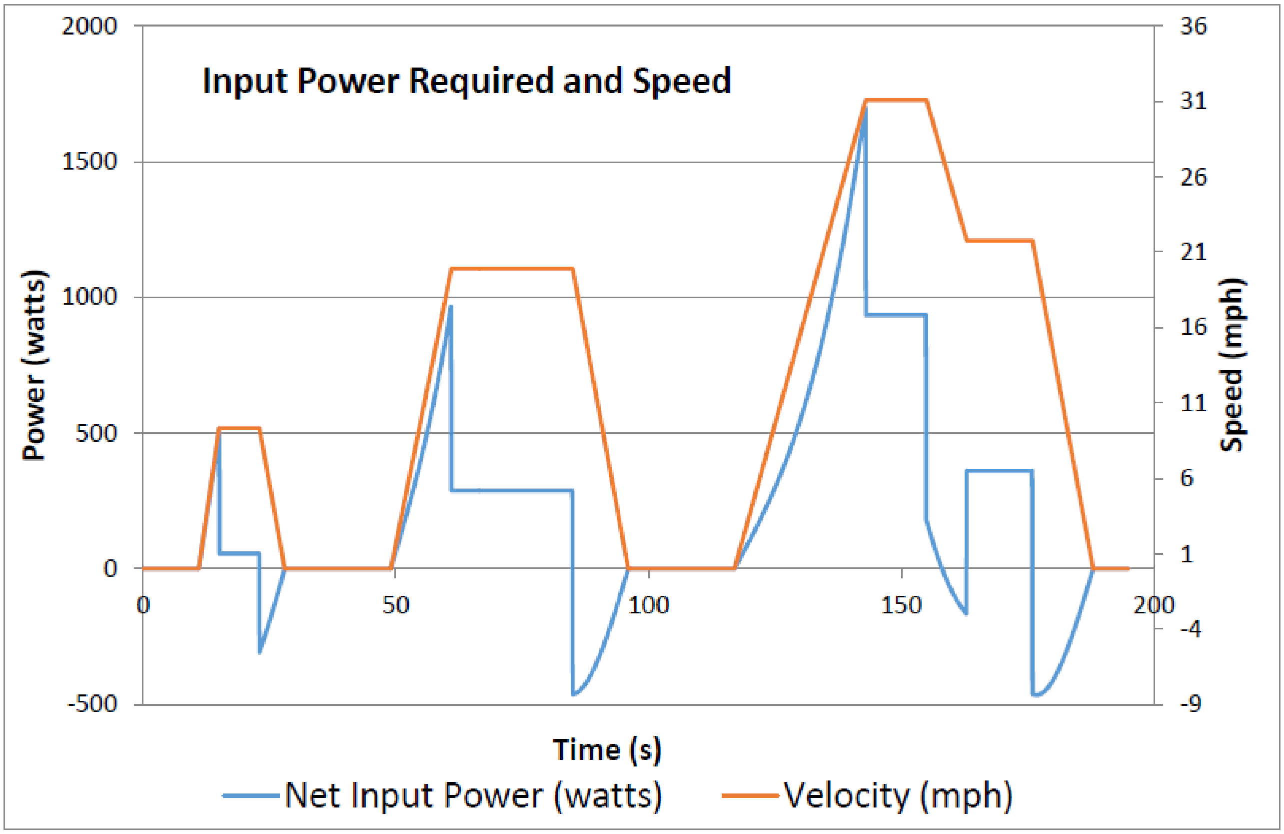


Fig 1.1: Energy graph

The places where blue line dips below zero in graph above is where the power requirement becomes negative; these are the zones where power regeneration is possible.

To calculate the potential magnitude of energy recoverable, we will analyze the total power used by bike during different intervals. Since

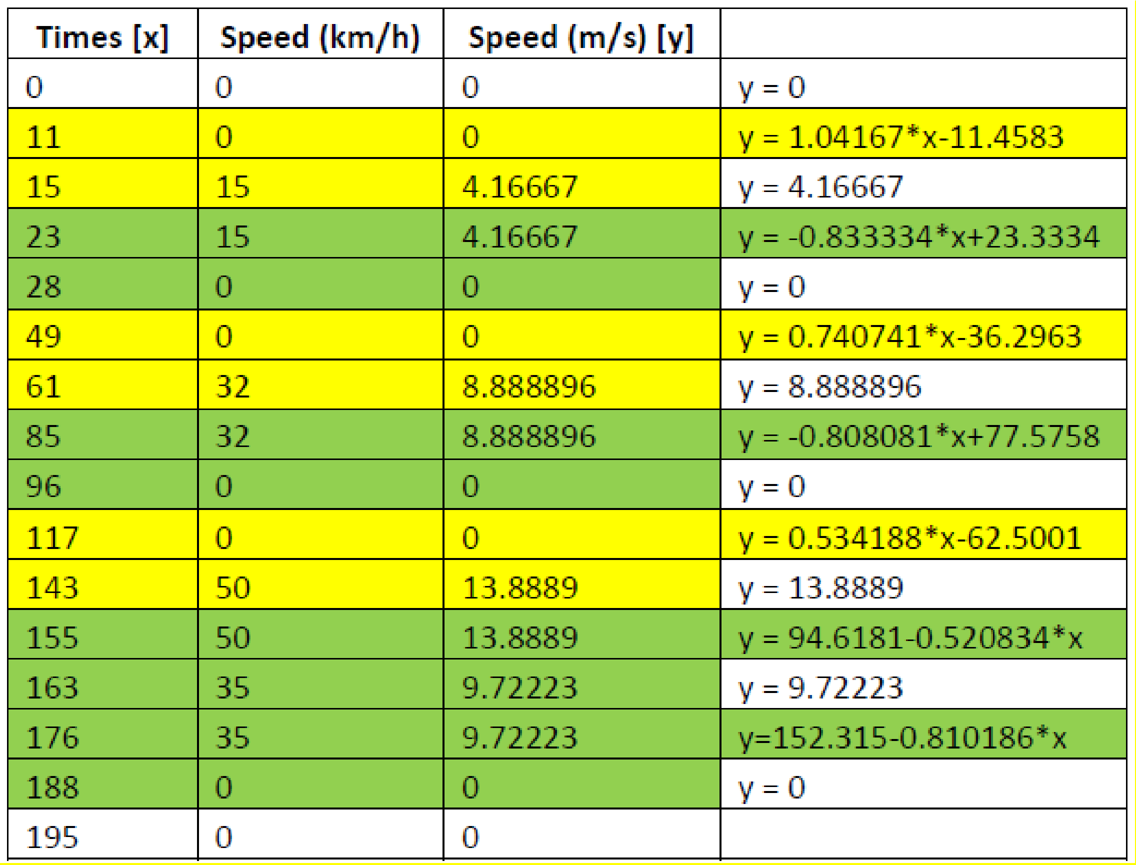
P=dE/dt

E=integralPdt

This can be done by taking a definite integral over separate intervals for which we previously have defined equations.

E=0-195integral((1/2(A)(C.d)(v^2)(p) + mgu+ma)V)dt

As we have several functions to define velocity in terms of time, we made a table to record our values for each interval. The yellows cells represent the energy being consumed by the bike during acceleration and/or coasting, while the green cells show the energy dissipated by the bike, the energy that we aim to reclaim through regenerative braking.



Times [x]	Speed (km/h)	Speed (m/s) [y]	
0	0	0	y = 0
11	0	0	y = 1.04167*x-11.4583
15	15	4.16667	y = 4.16667
23	15	4.16667	y = -0.833334*x+23.3334
28	0	0	y = 0
49	0	0	y = 0.740741*x-36.2963
61	32	8.888896	y = 8.888896
85	32	8.888896	y = -0.808081*x+77.5758
96	0	0	y = 0
117	0	0	y = 0.534188*x-62.5001
143	50	13.8889	y = 13.8889
155	50	13.8889	y = 94.6181-0.520834*x
163	35	9.72223	y = 9.72223
176	35	9.72223	y=152.315-0.810186*x
188	0	0	y = 0
195	0	0	

Table 1.1: Energy calculations

As a result, we find that the simulated motorbike with regenerative braking requires about 38 kJ of energy to when passing through a single iteration of the UDC. If we run the simulation again without regenerative braking, we find that the motorbike uses about 46 kJ of energy to accomplish the same feat. This means that the cycle with regeneration uses about 83% of the power that the cycle without regeneration uses, or a savings of 17%.

This is an inspiring number, but it is also very misleading because it does not take into account any electrical or mechanical losses in the motor drive and regeneration systems of the physical motorbike. But it does, however, show that an efficient regeneration system could increase the efficiency of the motorbike, making it both more sustainable and environment friendly, as well as being cost efficient to implement.

1.5 Goals and Objectives

The initial goal of this project was to design, develop and construct an operational "Hybrid motorbike" or a motorbike that utilizes regenerative braking for energy regeneration. During the first phase of this project, which consisted of mostly research and the design process for the bike, the group decided to broaden the goal to two set deliverables:

1. A conversion kit, that works on 70cc motorbikes and equips them with regenerative braking
2. Working prototype without any major electro-mechanical concerns

The overall goal of this project was to manufacture and assemble a kit which can be mounted on a functioning motor bike and make it hybrid and improve its functionality with energy regeneration. From this goal we derived several objectives that needed to be completed in order for this project to be a success.

I. Designing and manufacturing a drivetrain with minimal losses which can handle the excess stresses acting upon it.
II. Designing and fabricating a circuit to control throttle which can moderate the current flow to control bike speed on electronic drive.

III. Making a braking circuit that functions as both a charge regeneration path and a light brake while working in conjunction with the mechanical brakes for added safety.
IV. Design effective heat dissipation systems from electrical and mechanical components
V. Design in a way that bike can reach a speed of 40kmph on electronic drive
VI. Powered to be able to bear weight and move an average rider of 80kg
VII. Operates on standard battery of 12 volts, which can be easily re-charged e.g. by UPS systems found in homes.
VIII. Make all alterations which are easily disassembled.

The cumulative completion of these objectives would result in a successful project for the team.

Chapter 2

Methodology

2.1 Concept Designing

The goal of this project was to convert an average mechanical bike into a hybrid bike which utilizes regenerative braking for energy regeneration. This goal was achieved by systematic completion of all objectives by using a mix of mechanical and electrical engineering. The methodologies employed to achieve these objectives are explained in more detail in following sections. Due to their nature, all the problems to be overcome and tasks needed to complete this project have been categorized into electrical methods or mechanical methods sections.

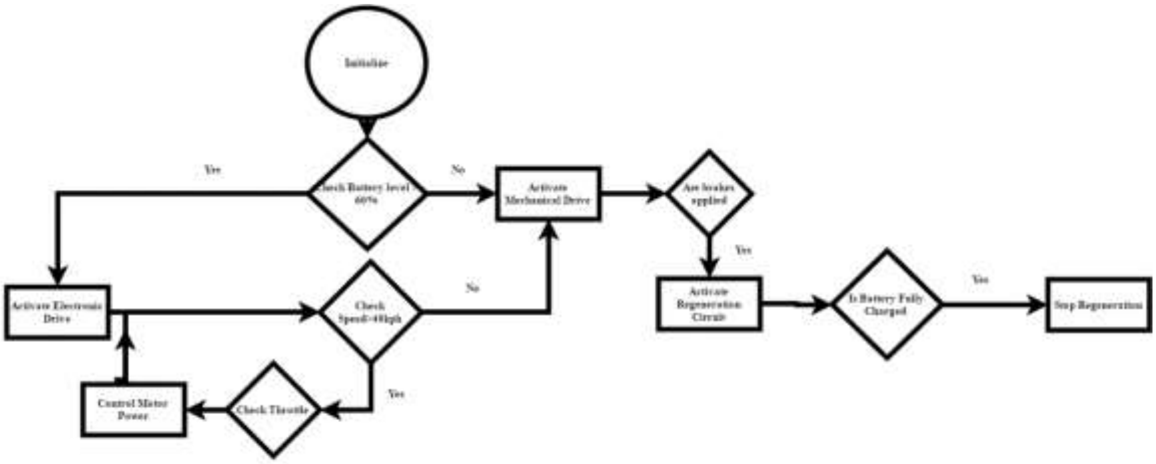


Fig 2.1: Logic diagram

2.2 Electrical Methods

To manage the electrical aspect of this project, we performed extensive analysis through simulation programs and applied the results to the design process for the circuits involved in the electric motorbike. The project group held themselves to established standards of performance and rigor. The materials and tools that were used are as follows:

Simulations

- Proteus ISIS
- MATLAB

Analysis and Testing

- Variable Power Source
- Cathode Ray Oscilloscope
- Digital Multi-meter

Proteus ISIS was used extensively in order to firstly design and then properly simulate the circuit design under ideal conditions. Later it was used for creating visual representations of the circuits and for developing the control circuits necessary for current limiting and transistor duty cycle with help of micro controllers and MOSFETS. During the analysis and testing phase, all results were repeatedly checked to ensure accuracy. Next step was to do live testing for which we used the equipment available in Control Systems Lab. By using Cathode-ray Oscilloscope, Variable power source, and Digital Multi-meter testing and analysis of the physical circuit was carried out. Designs were made on PROTEUS ISIS to create a model for a Printed Circuit Board implemented in the final design.

Major tasks for us were circuit simulation, component selection, design, and testing and analysis. Simulations had been carried out mainly through ISIS and then on smaller prototypes tested by using the equipment provided by the department. From these simulations and the accompanying value analysis, component selection was performed for the circuit elements and batteries from the easily available stock in Pakistan, mostly from Allied Electronics and IC Master.

After the components have been acquired from the appropriate suppliers, the circuit was assembled for lab testing to obtain ideal results in a controlled environment. From there, the prototype circuit boards have been manufactured and implemented in the overall prototype for testing. In parallel, we also fabricated the mechanical components of the motorbike to prepare the prototype for testing. As part of the analysis and testing, the motorbike was tested on industry standard pre-designated driving cycles to measure efficiency and to evaluate electrical and mechanical performance in real-world conditions.

From the lab testing and assembling tasks, results gathered concerning design criteria to determine whether regenerative efficiency requirements have been met. Lastly, compilation of the results was prepared for formal presentation to the public. Both Dr. Omar Ansari and Mr.Irfan worked cooperatively to achieve these tasks for the electrical aspect of the project.

2.3 Mechanical Methods

The final specifications were developed after several iterations, as more and more parameters became fixed due to design and power requirements and project specifications. Initially, design process began with establishment of basic specifications. This consisted of setting performance goals like speed of 40 Km/h for electronic drive and acceleration time of 10 seconds . Using standards such as ECE-15 Urban Driving Cycle, simulations were made to predict range and potential for regenerative energy. Then according to these considerations there was a need to decide upon the type of motor to be used. Selecting a motor type gave us more fixed parameters like torque, which were later used to design the gear ratios for required rpm and torque to drive the bike. The wheel rpm of the bike required were calculated as follows

Tyre Type = 2.5-17

Tyre radius = (2.5+17/2)5

Another major consideration during all design and component selection process was expenditure as we were attempting to remain within a reasonable budget.

Based on selection of motor and generator, a drive train design was made which could be mounted on the chassis of a 70cc bike. Iterations of drivetrain and component mountings were made in parallel until a suitable design was achieved. Most important considerations while making these design iterations were cost, ease of manufacturing and compatibility with the motorbike chassis. CAD models of the designs were made and analyzed with use of software like

SolidWorks, Matlab, and Microsoft Excel. Many designs were rejected on basis of space limitations, power loss considerations and impracticality of manufacturing.

After several iterations, a final design was selected which was satisfactory in aspects of design considerations. When the design was finalized, the manufacturing process began, from the alteration of the motor itself to make it fit in our design. A more detailed manufacturing process was developed with lots of emphasis placed on using as many off the shelf components as possible.

All manufactured components were tested as they were manufactured, and then the entire assembly was tested after the prototype was finished. This was done to ensure that all components surpassed the standards that were set out in the beginning of the project. The drivetrain, as well as, mountings for the motor and the generator were found to be of sufficient reliability and functionality. The vibrations caused by electronic drive were a major concern for the drivetrain, therefore, specially enforced mountings were generated which would dampen all vibrations. The final assembly was tested against the theoretical calculations to measure the real world performance of the hybrid bike and especially its regenerative braking.

2.4 General Group Organization

While this project group was not massive, it still consisted of members of both sections and therefore some formality of organization had to be maintained throughout the project. Daily meetings between the group members as well as weekly meetings with the advisors, along with extra meetings as necessary, were scheduled throughout the project duration to maintain progress and provide an open forum for communication, advice and recommendations on every aspect of the project. Various media were utilized to help schedule and regulate these meetings as well as maintain an open means of communication between the team and advisors.

- Dropbox
- Facebook
- Microsoft Office, PowerPoint
- Google Calendar

For general group communication and organization, Microsoft Office has been heavily utilized, specifically for Word and Excel, while Microsoft PowerPoint has been used for making Gantt chart to maintain the FYP group. The use of Google Calendar is primarily to keep the Final Year Project members updated on the active schedule, and for notification of any planned meetings. Their schedules were exchanged to set these meetings by using Facebook messages to establish common free time. Dropbox had been used for management of data and ease of project collaboration between all members. Skype was scarcely used but it was very helpful during extended breaks to keep the team in communication for full meetings together.

Chapter 3

Design Criteria

3.1 Brief description

In this project, there were several aspects of mechanical and electrical design that synergized with each other to create this hybrid motorbike equipped with regenerative braking. The drivetrain required intensive stress and power analyses that allowed the electrical engineers to optimize their control and throttling circuit designs. In addition to that, electrical considerations determined the physical design of the motorbike to account for component placement and weight distribution. Also the braking system had to be smart and use a conjunction of mechanical and regenerative braking for maximum effectiveness.

3.2 Powertrain

Since the control of this system is almost completely electrical, the drivetrain must be a closed system from the controlled motor to the rear drive wheel. Analysis began at the start of the project with this system. First, the required power had to be realized for the cruising speed to be met. Consideration of the various forces working against the bike must also be taken care of. After that the remainder of the drivetrain could be designed, including the required gear and sprocket ratios, strength required of the various parts, and the mounting materials that will hold them in place.

3.3 Power Requirements

The decision for the motor that would fit the motorbike design specifications was between DC brushed and brushless. Brushless motors are much more efficient and less susceptible to wear than brushed motors; however they are generally more fragile and much more costly. The brushed motors are relatively inexpensive, tough and reach full torque when not moving, but they will wear out at a much quicker rate. Another significant difference between the motor types is their function under motor braking. A brushless motor acts as an alternator under braking, which outputs the power in AC, while a brushed motor acts as a generator, which can output AC or DC power. For the electrical system of the motorbike, a DC output is preferred by the motor for many reasons. The batteries can only store a direct current, so the regenerative braking aspect would not work under AC conditions. Therefore, the system is much more efficient with a DC brushed motor, due to its output current. A converter system could be implemented with a brushless motor to create a DC output by the motor; however that would require more parts and money, as well as decrease efficiency due to additional losses in the increasingly complicated system.

Following this logic, a brushed PMDC motor was selected, however due to lack of cheap charge controllers available in Pakistan, it was found that using an alternator in conjunction for regenerative braking, with separate gear ratios, will be more cost efficient.

Several preliminary calculations were performed to check the feasibility of the project. These calculations are based on a total estimated load weight (motorbike and rider) of 1800 N. That weight is based on initial component selection and average weight of a rider and the acceleration due to gravity. A motor voltage of 12 V is assumed for simplicity of electric systems.

The method to determine the power required to move the motorbike mass to a certain speed of 40 kmph is as follows:

The power required by the rider, or in this case the motor, to move the weight of the motorbike up to a steady 40 km/s is calculated by summing the resistive forces on the vehicle and multiplying that sum by the speed. There are three major resistive forces that act on the rider and motorbike.

3.4 Wind Resistance

The wind resistance on the rider and the motorbike is caused by wind drag and any other aerodynamic losses. Wind resistance (Fw) is calculated with the inclusion of the frontal area of the motorbike and rider (A), the drag coefficient through air (Cd), air density (ρ) and speed (v). This relationship is represented in the equation below:

$$F=1/2(A)(C.d)(v^2)(p)$$

The values chosen to calculate for Fw are based on the preliminary requirements at sea level, since this prototype will not be tested for use in any significant elevation changes. Therefore, the average young adult frontal area is about 0.5 m2, the default drag coefficient value for a rider on a bike is about 1.0 (unit less) with minor fluctuation based on rider positioning and the air density at sea level is 1.226 kg/m3. These values yield a wind resistance value of approximately 19.2 N (Newtons).

3.5 Rolling Resistance

The rolling resistance on the rider and motorbike is caused by the rolling friction of the road and bike tires. The variables that affect rolling resistance (Fr) of the motorbike are the force due to gravity from the rider and the bike (mg) and the coefficient of rolling resistance (Cr). This relationship is exemplified by the equation below:

$$Fr = mgu$$

Same as the values for Fw, the average values for these variables were considered at sea level. Hence, the mass of the rider and motorbike cumulatively is about 180 kg, the gravitational acceleration is considered constant at 9.8 m/s2 and the coefficient of rolling resistance for a rough but paved road, as many urban streets are, is 0.008 (unit-less). This yields a rolling resistance value of approximately 8.2 N.

3.6 Gravity Forces

The gravitational potential energy produced by power required to move up or down a slope is considered in the gravity forces on the rider and the motorbike. Gravity force (Fg) is calculated through the multiplication of the force due to gravity from the rider and the bike (mg) and the angular slope of the hill in terms of angle (sinθ). This relationship is symbolized in the equation below:

$$F_g = mg * \sin\theta$$

Following the previous resistive forces, the average values for the motorbike and rider weight as well as gravitational acceleration are used. However the value for the slope of the hill is more variable. In the power calculations, three analyses were conducted for no slope conditions

3.7 Required Power

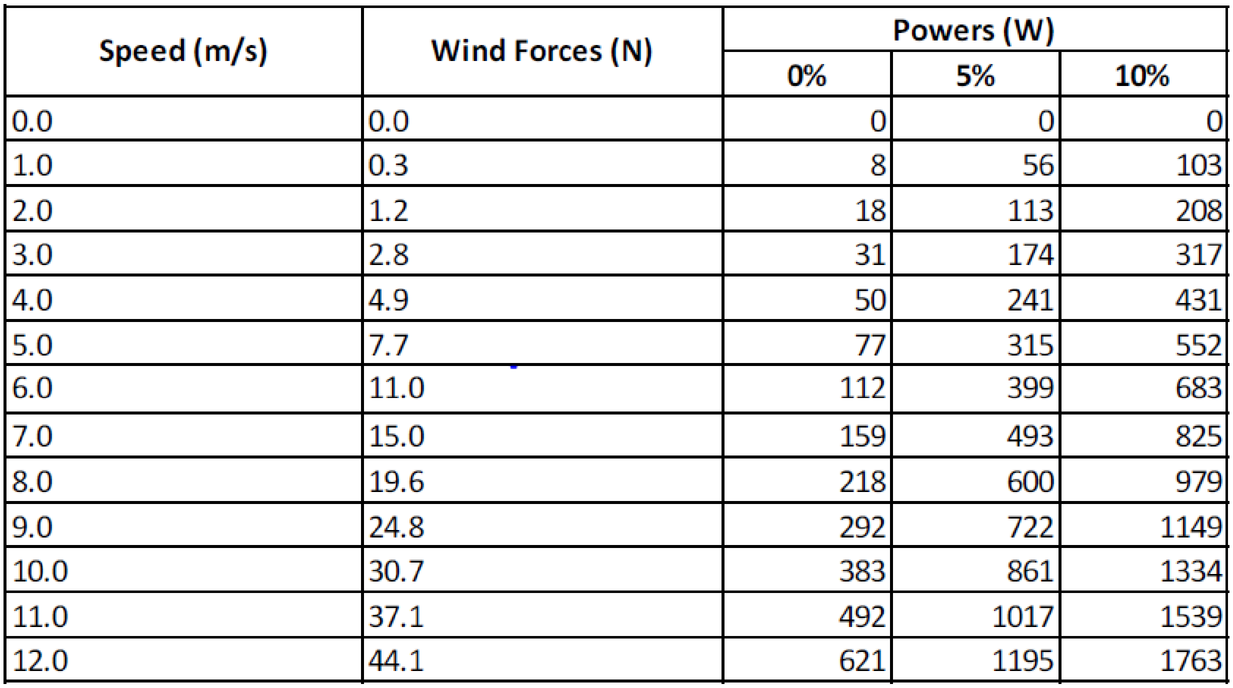
From the force values calculated for above, the power required by the motor to move the weight of the rider and motorbike up to 40 km/s on varying sloped roads can be calculated. In Table 1, the individual factors can be seen as well as the force values and final power values for the varying grades.

Tyre type	2.5-17			
Tyre radius	r	2.5+17/2	0.2794 m	
Speed	V	40 kph	11.11 m/s	
Drag coefficent	CD	0.3		
Width	w	0.760 m		
Height	h	0.995 m		
Frontal area	Af	0.7562 m^2		
Mass of Bike	m	183.5 kg		
Coeffiecient of kinetic friction	u	0.013		
Density of air	P	1.22 kg/m^3		
Drag force	Fd	0.5*Cd*P*V*V*Af*0.85	52.179 N	
Tyre Friction Force	Fr	m*9.81*u	23.4 N	
Total force	Ft	Fr+Fd	75.579 N	

Rpm on tyre	Nt	V/r	379.716 N	
Gear Ratio	Gr	3 :1		
Rpm on Engine	Ne	V/2 pi r *Gr	1140	119.38 rad/s
Tyre torque	Tt	Ft*r	21.116 Nm	
Engine torque	Te	Ft*r/Gr	7.038 Nm	
Power	Pw	Ne*Te	840 W	

Table 3.1 Average Conditional Values for Hybrid Motorbike

Our calculations of all these factors yield an exponential relationship between the powers necessary to move this motorbike to various speeds. Below is a table displaying the varying powers required to accelerate up to maximum speed for the motorbike at both 0, 5 and 10% slope gradients



Speed (m/s)	Wind Forces (N)	Powers (W)		
		0%	5%	10%
0.0	0.0	0	0	0
1.0	0.3	8	56	103
2.0	1.2	18	113	208
3.0	2.8	31	174	317
4.0	4.9	50	241	431
5.0	7.7	77	315	552
6.0	11.0	112	399	683
7.0	15.0	159	493	825
8.0	19.6	218	600	979
9.0	24.8	292	722	1149
10.0	30.7	383	861	1334
11.0	37.1	492	1017	1539
12.0	44.1	621	1195	1763

.Table 3.2 Varying Powers Due to Increasing Speeds

Graphical representations of these relationships are displayed below for the three varying slopes. Notice the power required to accelerate to full speed at a 10% slope is about three times that of the motorbike at a 0% grade.

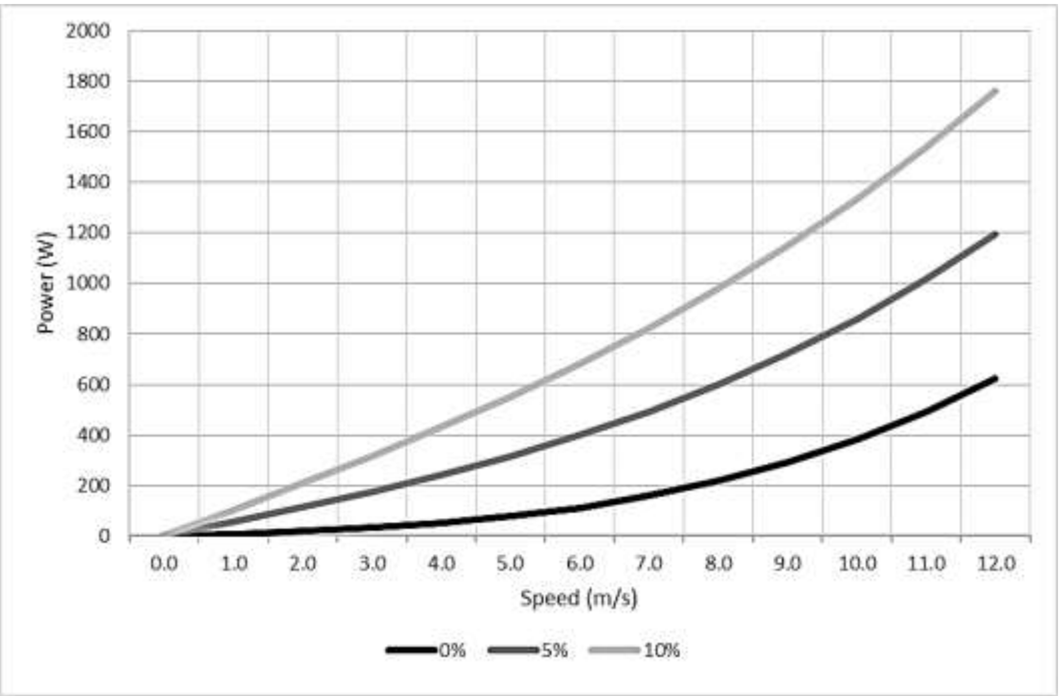


Fig 3.1 : Power vs speed graph

3.8 Motor Drive Circuit

The motor drive circuit is required to provide 12V and 100A to the selected DC brushed motor. The source will be a standard 12 volt battery, but due to size requirement, of a much larger size than the default motorbike batter, with simplicity in mind. Therefore circuits designed will need to be able to handle high amperage to counteract the low voltage being used for ease of design. A circuit will be selected that will effectively handle the high current, and also handle the power requirements of the motor.

3.9 Braking Regeneration Circuit

The requirements for the braking regeneration circuit are that it needs to be configured to maximize use of the alternator as a voltage source in order to capture energy that would otherwise be lost to friction of mechanical braking. The braking regeneration circuit must allow that this captured energy be safely directed back into the battery bank, without damaging the source. The braking regeneration circuit must also provide a safe and moderated method for deceleration.

3.10 Gear Ratios

The ratio between motor shaft rpm and rear wheel rpm was to be determined by a gear ratio. This gear ratio should produce the bike’s desired cruising speed at the motor’s optimal operational speed. Based on the performance map of the selected motor, a gear ratio will be selected such that the cruising speed of the bike is 11.2 m/s. A separate gear ratio will be chosen which connects the alternator with the motor, to allow the alternator to provide energy regeneration at much lower range rpms, and this was selected by constraints of manufacturing.

3.11 Control Systems

The control systems on this bike are a result of the need for user operation of the motor control elements. A variable resister embedded in throttle has been selected as the method for user interface to these elements. Due to the output level of the throttle being observed as a variable potential difference by the micro controller, the analog circuitry needs to handle the conversion from that voltage level to a duty cycle on output waveform. Additionally, the frequency of the

PWM duty cycles need to be kept fairly high so that the person riding the bike does not feel the jerks from varying throttle.

The bike is a hybrid bike and it consists of three modes, Electronic drive, Mechanical drive and Regenerative braking. Control systems need to be designed to switch between the first two drive modes using a mechanical switch which is controlled by the user himself, and between the braking and driving circuits using 3 inputs, the clutch, the front brake and the rear brake. Activation of any of these inputs will activate the regenerative circuit and regenerative braking will be applied.

3.12 Parameter Tolerances

The analog control system parameters are dependent on the motor control circuit requirements. For the motor and braking systems, the connected output of the control circuit network needed to be a square wave pulse with a variable duty cycle driving the gate pin of a power MOSFET. The frequency of this square wave pulse needed to be within 25% of the rated 1 kHz in order to meet tolerance, which allows for component errors as well as easier replacing of components in the design.

There was no restriction in this circuit design towards current limitations, battery selection or component tolerances aside from rated limits on the component data sheets which was 12 volts and 400 amperes for the MOSFETs.

3.13 Throttle Circuit

The brake circuit and acceleration circuits use MOSFET switching to control the amount of energy that flows from the motor to the batteries and from the batteries to the motor respectively. When designing these circuits, the switches were toggled at a frequency of 1 kilohertz, but it was decided that the duty cycle of the pulse used to toggle the switch would be left up to the user to control. If the user toggled some throttle device then the pulse width of the square wave input to the MOSFET switch would be modified to reflect this user interaction. The end result of a change in duty cycle is a change of average current level being provided to the loads in both the acceleration and braking modes. This feature is especially useful if the user, say, decided they didn’t want to go one speed all the time.

3.14 Challenges in Design

We encountered many design challenges during the design phase of this project. This section will be split up into two major sections so that the design challenges are easier to follow. This section will be further broken down to illustrate the design challenges posed in the creation of the power circuits and the creation of the analog control circuit.

3.15 Motor Drive Circuit

The electrical drive train, as the reader may recall, serves two purposes: the first purpose is to power the motor, and the second is to take energy from it and store it back into the batteries. The challenges faced in this design consisted of the selection of circuits to be used for both motor and braking modes, determining which components fit within current tolerance to avoid overheating, deciding on a main power source and chemical composition of that source, and designing around a specific motor with strict limits and operation requirements.

The selection of circuits to be used for motor and braking modes involved determining the method for obtaining the output that the motor requires to run. This output could either be DC-AC-DC transformation or DC-DC conversion, based on the selection of a DC brushed motor. Then, the method for how to feed charge back into the battery over the course of a braking cycle had to be determined as well.

Determining component current tolerance did not occur until later in the project when the circuits were chosen, but the estimated current capacity required for components on the primary side of the motor circuit was 100A according to wiring specification.

Also for regeneration, there was a separate challenge because using a single motor for regeneration during braking, as well as using it to power was highly inefficient and therefore not viable. Using a separate dedicated alternator for this task required conversion of power form AC-DC as well as gear ratios for the alternator to work at maximum efficiency and space on the bike to house an alternator.

The main power source needed to possess a high battery-life to weight ratio, high charge density, and the ability to accept charge back into the cells without damaging the batteries. The chemical composition of the source mattered immensely when determining which battery to use due to potential hazards some compositions may incur that need to be observed.

The brake and motor circuits also needed to be designed around the specifications of the motor and the alternator so that the proper component values could be chosen, and simulated analysis could take place before the construction and testing of the circuits.

3.15 Analog Control Circuit

The analog control circuit, as mentioned earlier in this section, needed to switch between power circuit modes of operation and control the duty cycle of a pulse in each mode. The challenges faced in this design included the selection of an oscillator, the method of switching modes, the connection to the power circuits, and determining the method of modifying the throttle DC voltage bias level into a duty-cycle modifiable square wave pulse.

The selection of the oscillator was limited to a device that would provide a frequency within tolerance and a relatively noise-free pulse at sufficient voltage levels to drive the power circuits.

The component used for the connection to the power circuit was limited to a device which could handle the primary side current of the motor circuit. A switching system had to be implemented to handle the switching to regenerative braking to engage the alternator only when needed to avoid unnecessary electrical load on the motorbike during driving.

Chapter 4

Component Selection

This section will discussed the details and methodology for selection of the various components for the construction of the motorbike.

4.1 Motor

The motor selection was based on calculated requirements for power. We made a selection, Starter 1.4 hp motor, to provide the power needed to maintain full speed in a no slope situation with a safety factor of one and a half. This gives us a generous amount of extra power to work with, and allows us to run the motor below peak power output to boost efficiency. The following graphs show the functioning of our motor.

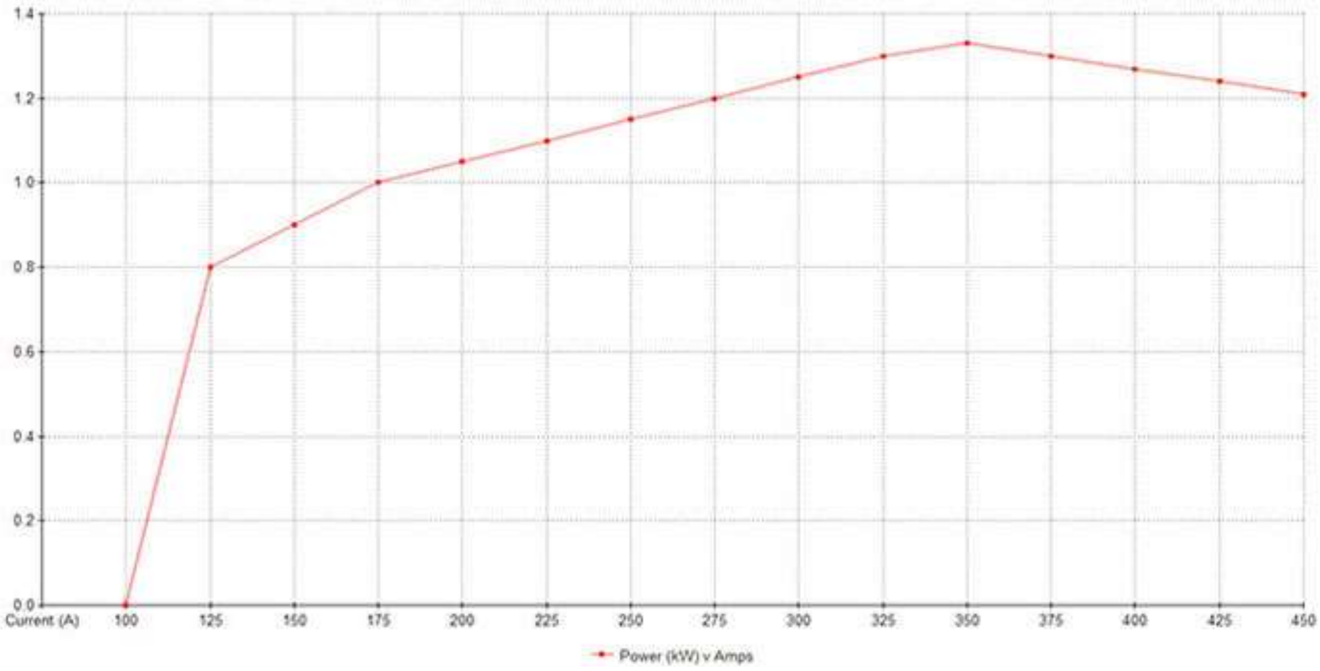


Fig 4.1: Current vs power

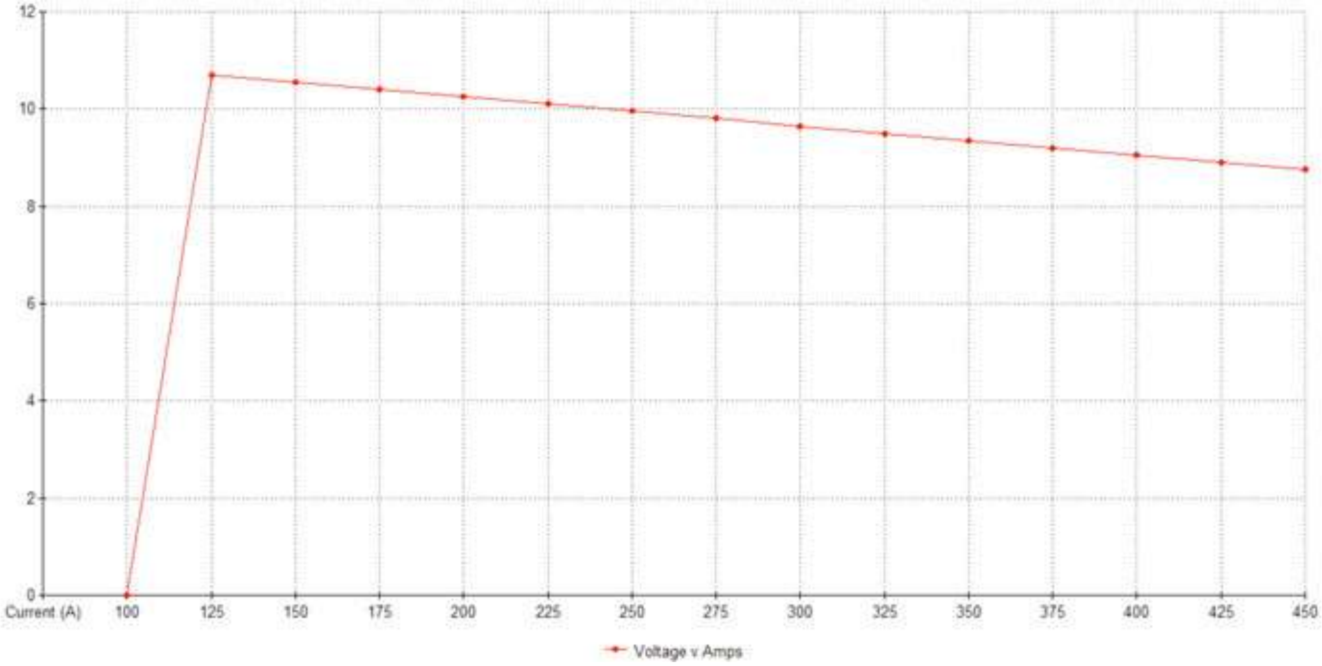


Fig 4.2: Voltage vs Current

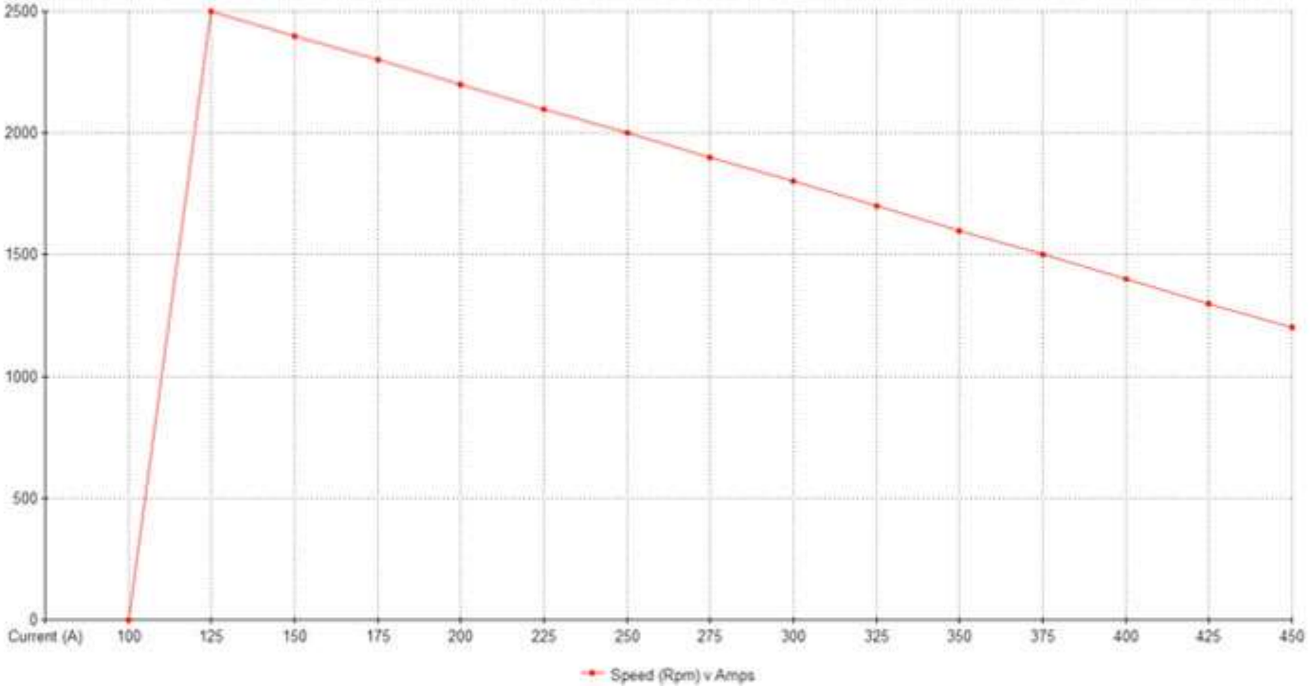


Fig 4.3: Current vs speed

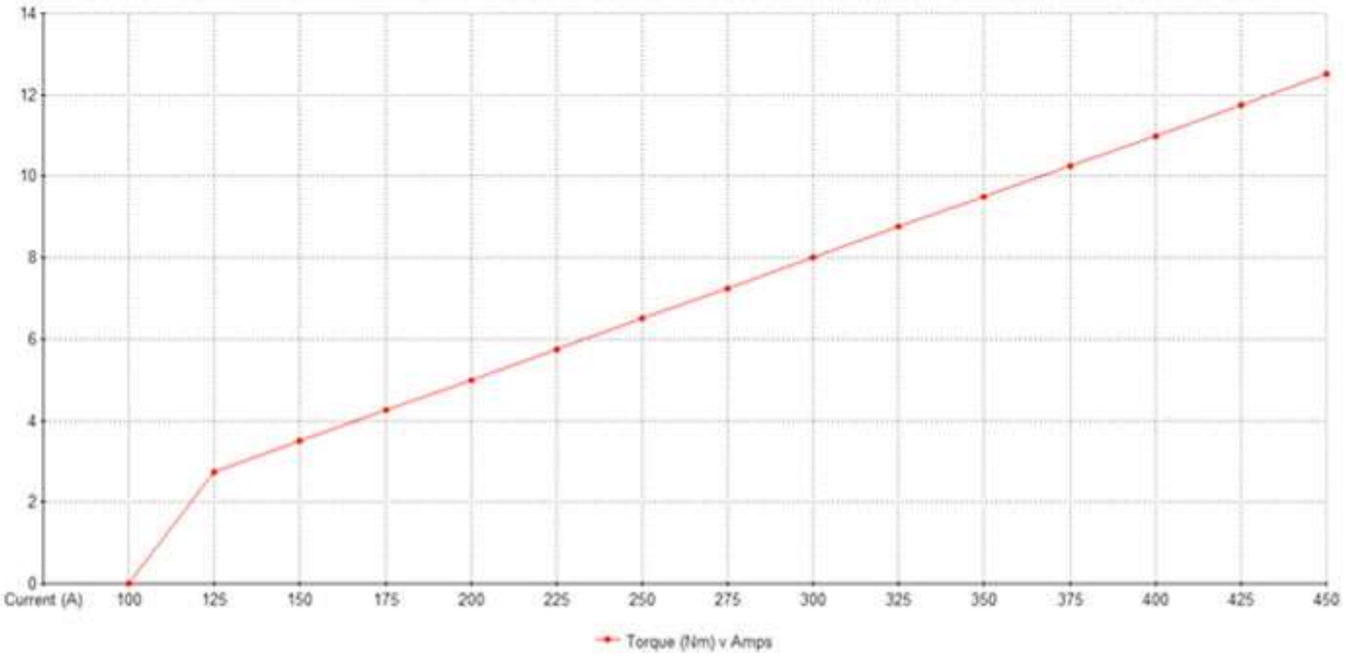


Fig 4.4: Current vs Torque

This table demonstrates that based on the specifications we do have for the motor, the rest of the motor specifications fall in line with what is required for the project. Shown below is an rpm/torque curve of a standard electric DC motor, like the one we are using. Some scaling is incorrect, but the curve is the same.

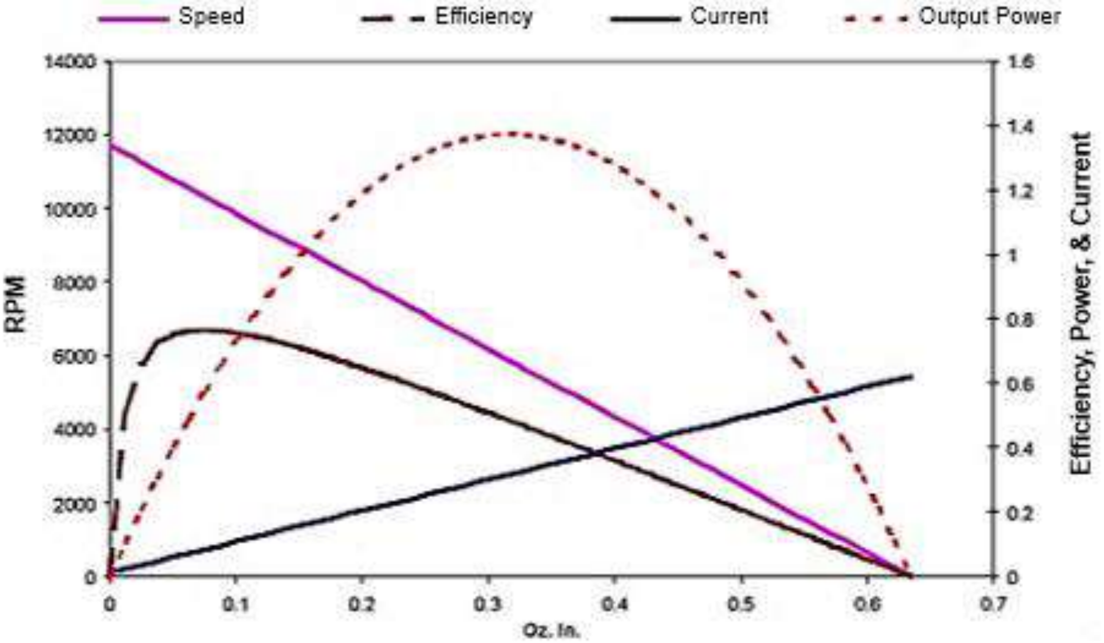


Fig 4.5: Rpm vs Efficiency

After scaling we can see that the motor's maximum rpm is 6000, we found the maximum efficiency of the motor to occur when running at roughly 4500 rpm. Using that as a metric, we set the gear ratios in the drivetrain to produce the bike's cruising speed when the motor is running at maximum efficiency.

4.2 Gears, Sprockets & Chain

Based on the calculations above and the size of the bike's rear wheel (a standard 23 in), we determined that the overall gear ratio should be about 1:15. This reduces the cruising rpm of the motor, 4500, to 300 rpm at the rear wheel.

Also, there needs to be a secondary gear ratio to spin the alternator at even high rpm. Therefore the entire gear ratios could not be implemented in one step. A series of two reductions was designed. The first was performed between a gear on the motor shaft and a gear on an axle placed through the bottom bracket of the bike. This reduction had several interesting constraints placed on it due to the diameter of the motor itself and the location of the bottom bracket.

Fig 4.6: Power Train

As it is clear from the diagram, the upper sprocket (Motor) is same as the other sprocket on left. This was done deliberately to decrease the amount of manufacturing required and to reduce the alterations being done and the overall cost of the project. This gear ratio is the standard 6:41 of that of the motorbike engine and rear wheel. A secondary ratio was made by use of pulley between the motor and the alternator. This was of 1:2 gears, and it was restricted by the manufacturing constraints and a smaller pulley for belt of required thickness would need to be specially manufactured instead of being bought off market. This produced an approximate final gear ratio of 1:15 which is the required result.

While we had option of using any gear ratios we wanted, our objective was to try using as many stock parts as possible and this confines our choice considerably. Fortunately, we were able to choose gear ratios that were suitable for out usage.

4.3 Bearings

Bearings for the driveshaft were selected based on operational rpm of the bike, and the requirement for them to be flanged. We purchased MSC’s .5in ID 1.375 OD sealed flanged bearing. This bearing can withstand speeds of up to 2500 rpm, well above the 1500 rpm limit for the shaft they are situated on.

4.4 Batteries

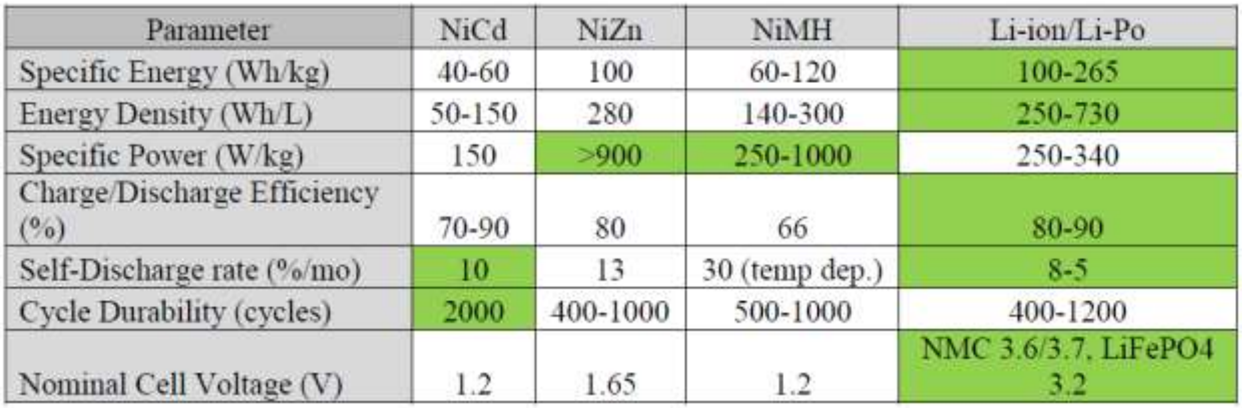
Batteries are the components that store electrical energy, allowing for the motor of the vehicle in question to run. There are two types of battery: non-rechargeable batteries known as primary cells and rechargeable batteries known as secondary cells. Both types of cells operate the same way through an electrochemical reaction involving an anode, cathode, and electrolyte to produce electrical current. With primary cells this reaction eventually runs to completion by exhausting all electrical potential within the closed system. However with secondary cells the process is reversible, thereby being able to be reused. Such secondary cells, also known as accumulators, can be found in laptop batteries, cellphones, flashlights, and other everyday devices that are either plugged in to a power outlet to charge or placed into a charging dock. For an electric motorcycle, high-capacity secondary cell batteries will be used; these will stand as the electrical analog for refueling to the chemical gasoline equivalent.

The material type of the battery determines the long term input voltage and current performance for and, as such, was of primary concern the ECEs. As seen in **Table 4.1,** value analysis was performed for this component. For the purposes of this final year project, a secondary cell is required due to the rechargeable nature. The main materials that allow recharging are nickel cadmium, nickel zinc, nickel metal-hydride, and lithium-ion/lithium-polymer; these are respectively listed as NiCd, NiZn, NiMH, and Li-ion/Li-Po on the battery analysis table. From this, material comparison was conducted with respect to specific energy, energy density, specific power, the charge and discharge efficiency, self-discharge rate, cycle durability, and nominal cell voltage.

Specific energy is energy per unit of mass, described in the units Wh/kg, and denotes a lighter battery as the value increases if the energy were to be kept constant. Energy density is the amount of energy stored in a specified unit of volume, described in units of Wh/L. An increase in energy density denotes a smaller battery if the intrinsic energy were to be kept constant. Specific power, also described as the power-to-weight ratio, is the amount of power in a system per unit mass. The charge and discharge efficiency is the percentage of energy you are able to retrieve from the battery after charging; it denotes overall efficiency of the battery as a system. Self-discharge rate is the amount at which a battery discharges without external interaction, and denotes how good the battery is at retaining its own charge. Finally, cycle durability is the amount of charge-discharge cycles that a battery can go through before the battery begins to display a significant charge capacity decrease and the output current characteristic begins to degrade.

After understanding the various aspects under review, value analysis for battery material type was conducted. Concerning nickel cadmium, the capacity is undesirable, and these batteries contain cadmium which is toxic to the environment. If the project is to consider an environmentally friendly solution to urban transportation, nickel cadmium batteries are not a viable option. Nickel zinc batteries are currently not widely available on the market, and the costs would overrun any potential benefit. Nickel metal-hydride cells have voltage that is lower than desired, a highly undesirable self-discharge characteristic and poor charge/discharge efficiency. Finally, Li-ion/Li-Po was selected as the best battery material type to pursue since it excelled in most areas except cycle durability and specific power. However, with cycle durability lithium ion/polymer came in second behind nickel cadmium. Also, specific power only came in second to nickel zinc and nickel metal-hydride, and not by a large factor.

The table below illustrates the different material types under review. The green markers indicate the best or highest value of the specific parameter.



Parameter	NiCd	NiZn	NiMH	Li-ion/Li-Po
Specific Energy (Wh/kg)	40-60	100	60-120	100-265
Energy Density (Wh/L)	50-150	280	140-300	250-730
Specific Power (W/kg)	150	>900	250-1000	250-340
Charge/Discharge Efficiency (%)	70-90	80	66	80-90
Self-Discharge rate (%/mo)	10	13	30 (temp dep.)	8-5
Cycle Durability (cycles)	2000	400-1000	500-1000	400-1200
Nominal Cell Voltage (V)	1.2	1.65	1.2	NMC 3.6/3.7, LiFePO4 3.2

Table 4.1. Battery Analysis for Electric Motorbike

Performing value analysis for Li-ion/Li-Po batteries, the main values under analysis were voltage, capacity, and cost. It was a requirement that the batteries be secondary cell lithium configuration. The main issue encountered was finding appropriate battery charge capacity values at an affordable price. However, the batteries available at the electronics company Osaka were within the desired range.

The selection is as follows:

- Battery – 12.8Ah
- Rechargeable lithium battery, 6 cell

Chapter 5

Electronic Control Systems

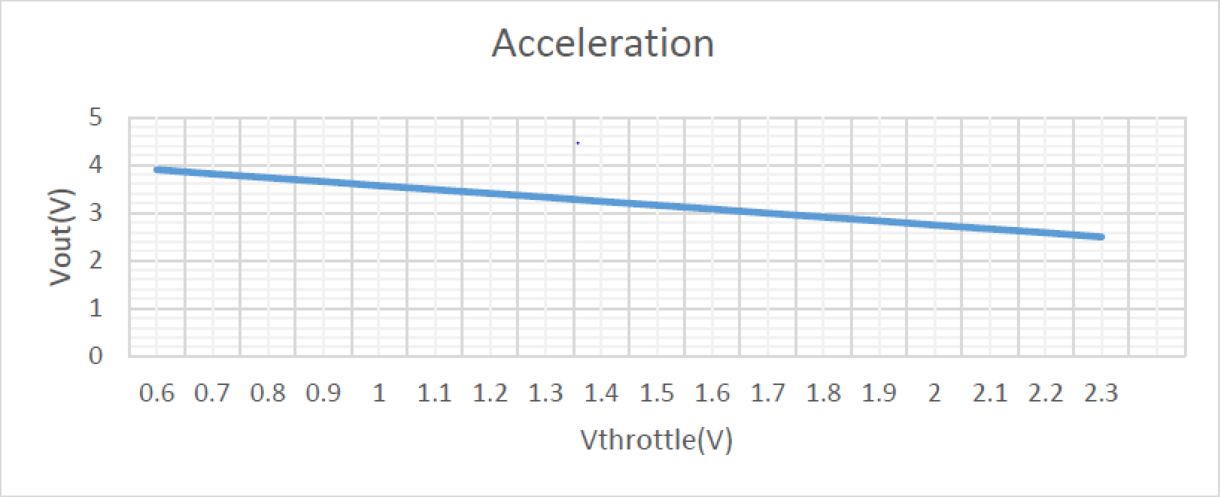
5.1 Brief Description

The control circuits required a fair amount of component analysis and computation in order to achieve values. When designing this circuit several decisions were made without one explicit reason to use a specific circuit type over another, so everything that is seen from this point on is what could have been done differently or better. First it was necessary to produce a modifiable square wave. It was done using a MOSFET control module, MOSFETS rated at 120 amperes each, Arduino Uno micro controller and a 10kohm potentiometer.

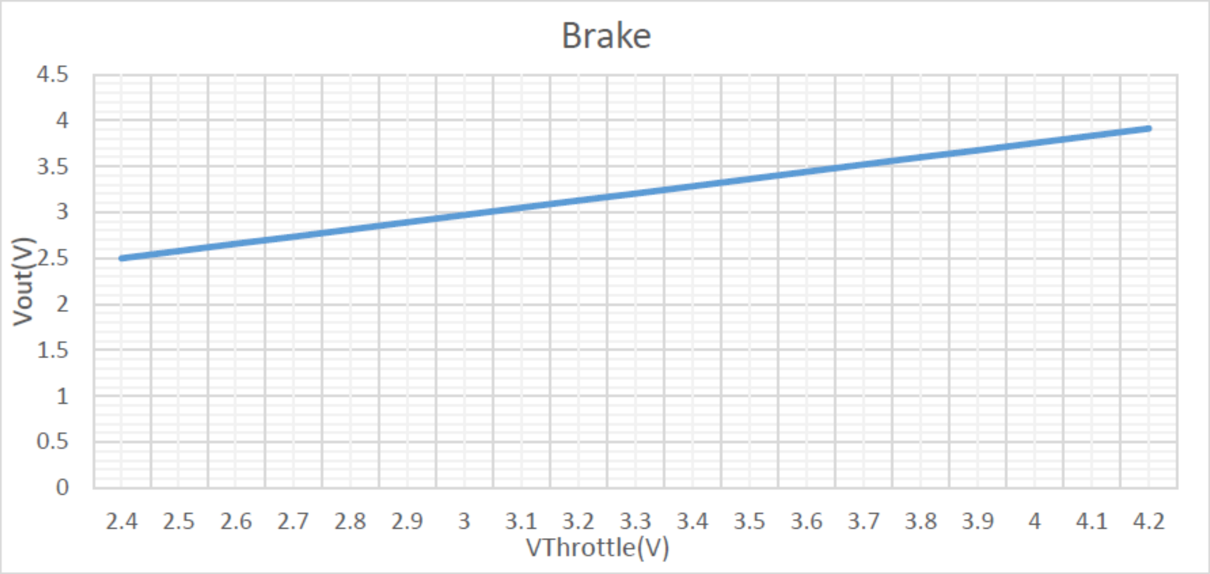
5.2 MOSFETS

It was decided that to control the speed of the bike, fast switching will be required and this can be achieved through use of MOSFETS. The current on free run was 35 amperes by the motor. Under the load of the bike this current goes up to 100 amperes with impulse current reaching up to 400 amperes. For this purpose it was decided that 3205 MOSFETS should be used to control the pulse width modulation of the duty cycle.

Voltage required during acceleration was plotted on following graph



And for braking



Figures 5.1, 5.2. These two graphs display the ideal mapping of throttle voltages to output voltages used by a comparator to generate a modifiable duty cycle.

The PWM of the duty cycle was simulated and the resultant required wave looked like the following diagram

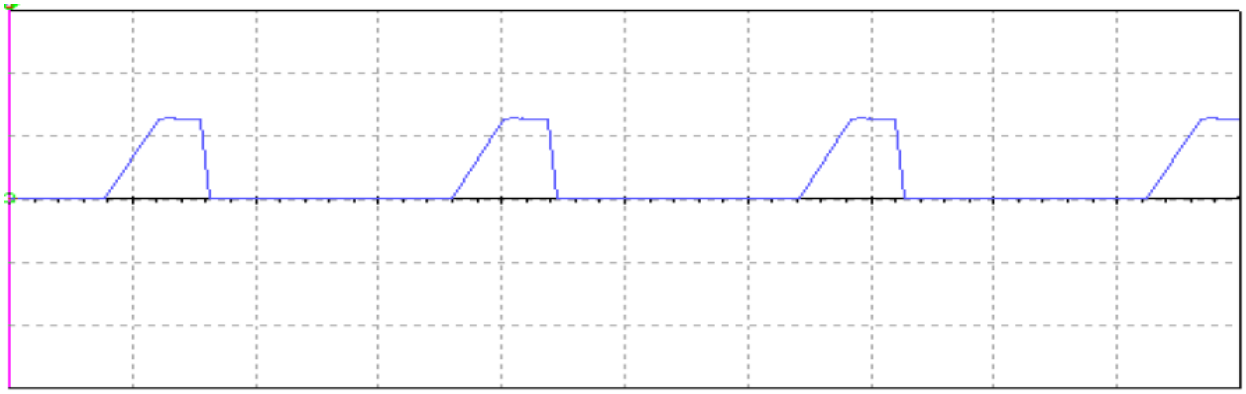


Figure 5.3. Roughly 10% duty cycle @ VThrot = 12 Figure 5.3. Roughly 10% duty cycle

5.3 MOSFET DRIVER MODULE

To control the MOSFETS a driver circuit was required. For our purpose we needed one that could be found easily and will be durable. For this we decided to buy a 4 channel MOSFET driver module. The already placed MOSFETS on the PCB were removed and higher amperage MOSFETS were soldered on it to make it suitable for our use.

5.4 Micro-Controller

We decided to use Arduino UNO because it is cheap as well as easy to use. The has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. Therefore it was ideal for our manipulation.

Chapter 6

Final Design

6.1 Mechanical Design

The final mechanical design encompasses the modified frame, the drivetrain, and all the structural and mounting components that allow the bike to function.

6.2 Frame

The frame addition is a new frame section behind the bike chassis. The frame addition was constructed out of angled iron, allowing it to be welded to the similar chassis of the bike frame. Additionally, there are several bars normal to the frame that serve to support the gears and plates that holds the drivetrain together. One of the tubes on the frame addition also serves as the support for the control box

Once the frame was fabricated, the CAD model had to be adjusted to account for differences between the model and what we actually received. Most notably, the two longest bars on the frame addition were welded with their ends further apart, rotating the entire bracket upwards several degrees. This slight change required several design changes in the bike to account for more space required to handle both a motor and a generator instead of a single motor for both functions as initially designed

The advantage of this frame addition design is that it allows us to secure the motor where its weight will contribute to a low center of gravity for the bike without increasing the unsprung weight of the bike. This frame addition was designed to provide a platform for the motor to be mounted as high as possible for maximum chain wrap without interfering with the riding dynamics of the motorbike.

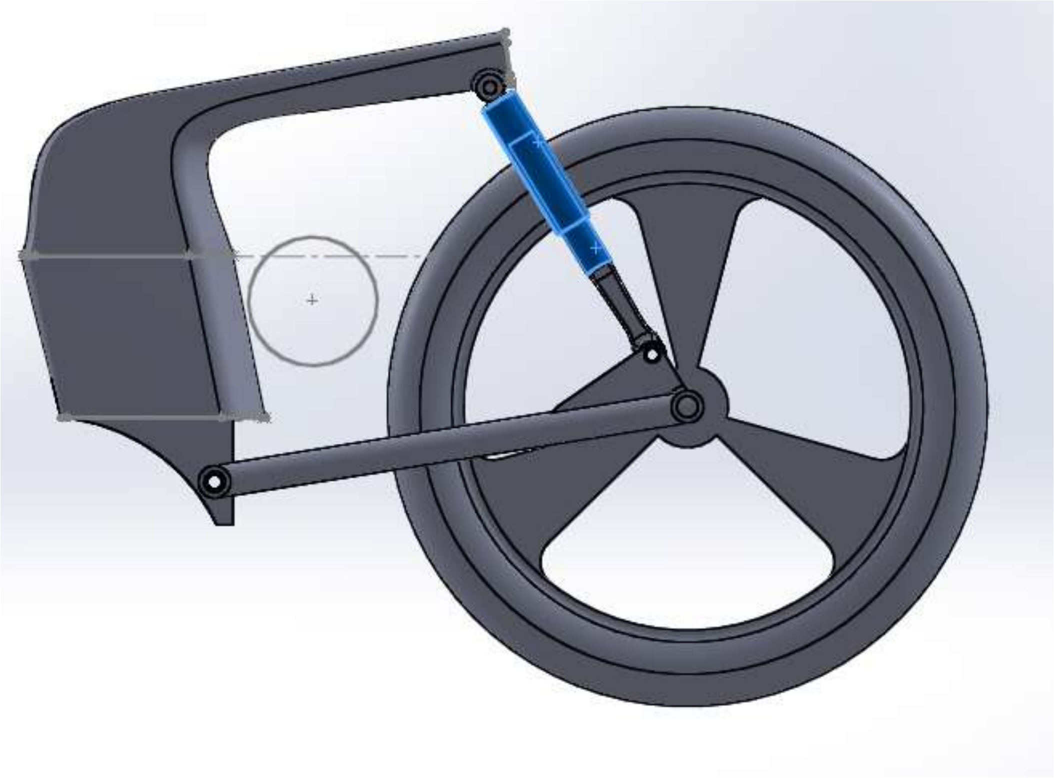


Fig 6.1: Motor location

6.3 Motor Mounting

Due to the dimensions of the selected motor, there was very little wriggle room on where the motor could be mounted. Additionally, the motor only has two shallow threaded holes mounted longitudinally along its belly, so it was determined that some side-to-side stabilization would be required. A plate with two slots in it was designed to be the primary mounting surface for the motor. The slots allow the motor to move forward and backwards during the mounting process to allow for loose tolerances and ensure contact between drive gears. It was decided that this plate should be steel, to allow it to be easily welded to the frame additions.

Originally, the frame addition was designed such that the motor could be bolted directly to the mounting plate and still be able to slide towards the bottom bracket far enough to let the gears mesh. However, because the measurements of the fabricated frame were non-trivially different than those of the CAD model, it was impossible for the motor to be mounted directly to the gear plate and still allow the gears to be in contact. Luckily, a motor cradle was necessary to limit rocking anyway, so the original motor cradle design was modified such that it raised the motor and allowed the gears to still mesh.

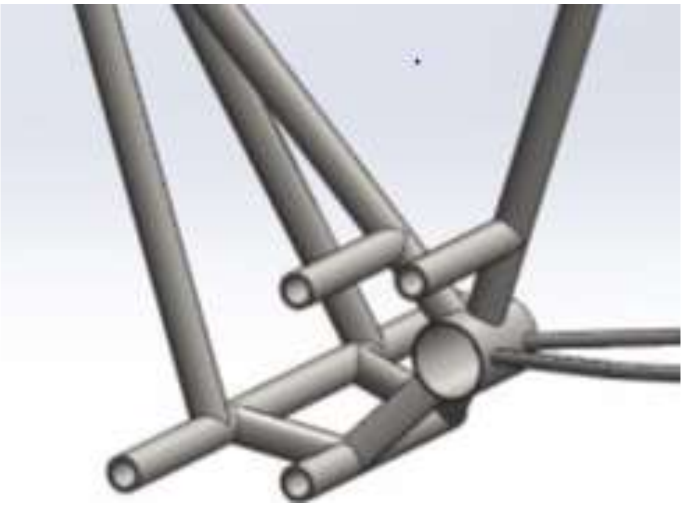


Fig 6.2: Frame

6.4 Drivetrain

The design of the drivetrain had two main goals. First, it must transfer power across the distance from where the motor is mounted to the rear wheel of the bike. It must produce a desirable speed at the rear wheel during the most efficient torque and power rpm band of the motor. To achieve these goals, and gear and sprocket reduction was selected. The gear/gear reduction is the largest reduction, and the sprocket/sprocket reduction covers the most distance. It also needs to allow for a connection between the alternator and the bike wheel to generate power during the braking process.

6.5 Gears

As is covered in Component Selection, two gears were chosen for the gear reduction based on several design considerations, most notably an output rpm of 300 on rear wheel. The gear chosen was the normal engine sprocket of a 70cc motor bike which is commonly available off the shelf. Because of geometric considerations having to do with the length of the motor, this gear must be placed at the end of a heavily cantilevered shaft.

To reduce bending stresses on the shaft, it was decided that hardened steel should be used as the shaft material due to its hardness and resistance to stresses. It was also decided that the gear should be machined and holes drilled in it to reduce the weight.. Before the gear was machined, finite element analysis was performed on the lightened design to ensure structural integrity.

Worst case constraints were set for FEA including the max load directly applied to one tooth tangential to the gear. The gear was fixed at its center. It is important to note that the highest stress concentrations do not change from those in an unmodified gear, that is, they are directly behind the tooth that the load is applied to. This indicates that the modified gear will still fail in the manner which it was designed, and therefore modifications won’t strongly affect the structural integrity.

After material removal, the gear ended up being about 60% lighter, thus reducing stress on the shaft.

6.6 Middle Shaft

The placement of the shaft in the drivetrain was determined by preexisting frame geometry. It was decided that the chassis of the bike should be utilized as the mount for the driveshaft, as it was already designed to handle high loads.

Fixing the drive shaft to the rear bracket also offered the advantage that on the original bike as there was an already existing sprocket and chain power transfer system in exactly that location. Therefore, a path for the chain was clear of any obstructions.

A steel stepped shaft was designed to hold the gear and sprocket in place laterally, and keyways were milled to hold the gear and sprocket rotationally. There are also steps to hold the shaft in place in relation to the bearings. This was to avoid dependence on set screws and to avoid the complications of fabricating a hexagonal shaft.

The flanged bearings that support the shaft are covered in more detail in Component Selection, but they were chosen to fit into the bracket made inside the motor mounting. A bearing collar that fits inside the motor was designed to provide a smooth and relatively flat point of contact for the bearings. The outside bearing works in tandem with the gear housing, discussed below.

Fig 6.3: Middle shaft

6.7 Gear Plate

The two bars above the bracket and the two parallel bars on the frame addition act as mounting points for the gear plate to hold the drivetrain. Angled iron rods are welded to make these bars, and provide a solid plane of contact for the gear plate to be mounted against. The outer bearing collar is mounted on the motor shaft which is welded to the gear plate which extends through a hole in the gear plate to provide a fixture for the clutch and the pulley attached to the shaft

Note that the entire shaft assembly is held together by use of joints made by welding. It was designed in that manner for ease of manufacturing and so that the individual parts like the gear plate are modular and desensitized imperfections in fabrication and then brought together to form a single large component. For example, the bearing collar can be located such that the drive shaft is normal to the bike frame, even if the gear plate is not precisely parallel with the frame.

6.8 Electronics/Battery Case

The electronics/battery case was designed to hold all of the electrical components necessary to run the motorbike. The main design considerations were flexibility, weight distribution, and convenience. It was important for this part of the design to be flexible because it had to be fabricated before the physical electrical components were done and their measurements were final. Therefore, it had to have enough room to fit a variety of sizes and shapes of circuit boards. This part was also to hold the batteries, so it had to allow them to be held as low to the ground as possible to keep the motorbike maneuverable in turns. Finally, this part must also be easy to remove so that the circuits remained easily maintained.

6.9 Final Motor Drive Circuit

The final motor drive circuit involved 2 circuits, a direct DC power to motor to drive it and a regeneration circuit which undergoes AC-DC conversion to make alternator output DC and suitable for recharging battery. The speed of the bike was controlled by the pulse-width modulation of the MOSFETs based on throttle by the user. The circuit schematic for the motor drive circuit is shown below.

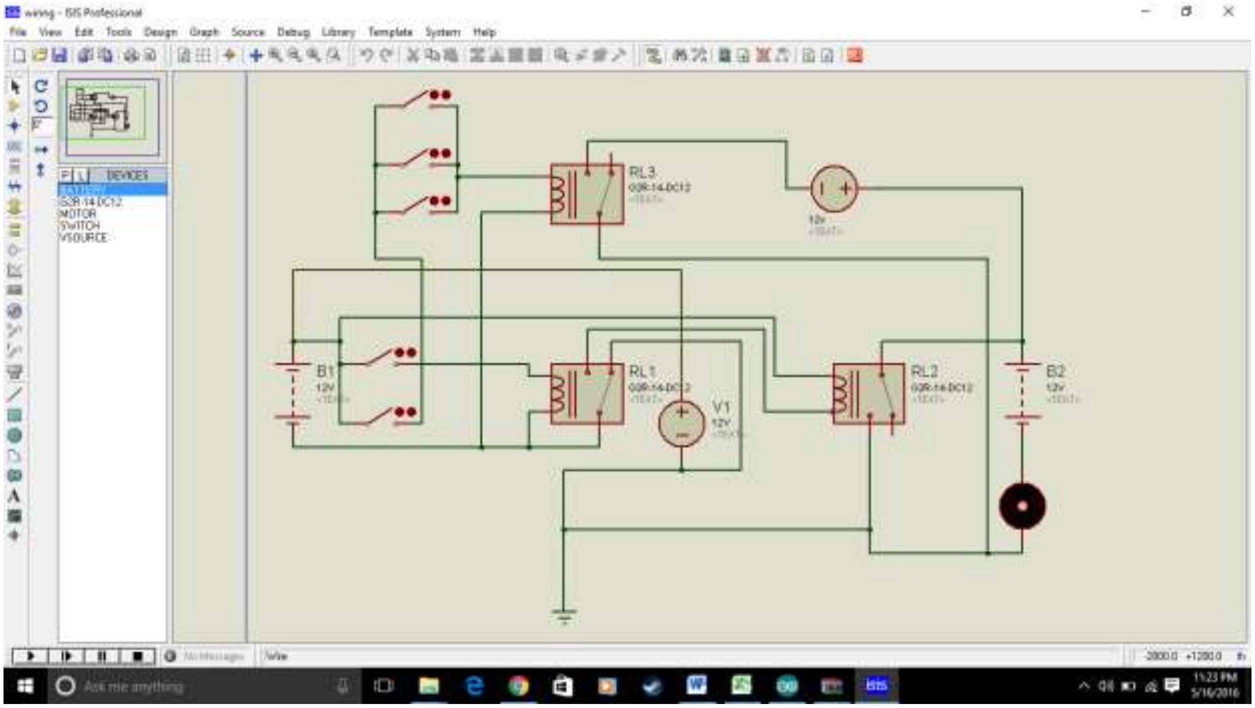


Fig 6.4: Circuit diagram Proteus

The battery source is indicated by a 12 volt battery which will be the large separate battery that we attach on our bike. There are 3 relay connections which control the circuit, the first relay switches the diving mechanism from engine drive to motor drive and vice versa as needed. The current when flows through the terminals at relay one engages the motor drive circuit and shut off the engine drive. This is to protect the lower amperage components of the bike.

The second relay is used to separate the lower voltage micro controller from the higher voltage circuit that drives the motor and does regeneration. This relay is operated by 5 volts and minimal current and its purpose is to protect the sensitive electronic components of the control box like Arduino Uno from being damaged by high electricity flow.

The final relay is used to control the switching between motor drive and the regeneration system. This relay was important because the body of the bike acts as common ground for electronics under normal use. However, during regeneration, the current flow is reversed and so is the polarity of the ground i.e. the body of the bike. To prevent damage to rest of the circuitry, this relay was used in conjunction with a diode so that reverse biased current does not flow at any point during the operation of the hybrid bike.

Chapter 7

Fabrication

7.1 Processes

Various methods and tools were used by both the electrical and mechanical side of the final year project team to fabricate the motorbike. These methods include:

- Soldering
- Wiring
- CNC Mill
- Manual Mill
- Drill Tap
- Hand Drill
- Manual Lathe
- CNC Lathe
- MIG/ TIG Welder
- Vertical and Horizontal Band Saw
- Angle Grinder
- Sheet metal bender

These tools and methods were used with the assistance of Manufacturing Resource Center workshop at SMME as well as from others workshops outside NUST. The following sections describe in detail how these methods were used to fabricate or adjust each of the individual components for the final bike.

7.2 Frame Addition

The additional tubing added to the frame was machined by lathe machines in MRC. The machining modifications to the individual weld pieces were too complex for the machinery at the welding shop in MRC therefore the welding from done from welding workshops in G-11 Rawalpindi. Special safety precautions had to be taken as the fuel inside the bike could ignite and cause explosion during the welding process.

7.3 Gears

The process of machining the tooth gear to mount it on the motor shaft was performed in lathe machines here at SMME. The group wanted to use a CNC machine. However, after consultation form craftsmen at MRC it was realized that this could be easily achieved on manual lathe and therefore decision to use CNC was changed. After a lengthy and surprisingly complex process to make hole in the gear itself, the gear was press fitted on the shaft and then welded to secure it in its place over the course of several hours. The weight of the gear was also reduced by 60% to make it lighter. After the gear was machined, it was further machined to perform surface finishing and to remove run-outs

7.4 Clutch System

A sprag-clutch was used and machined to form the clutch system to engage and disengage the hybrid drive mode. First the clutch was machined carefully to make a hole in its center without damaging its clutch mechanism. Then it was press fitted on the motor shaft and a keyhole was drilled in it so that the connection between the shaft and the clutch becomes rigid. This too was done on lathe and mill machines inside MRC at SMME. Care had to be taken to machine the clutch as it required a interference fit and tolerances were low.

7.5 Pulley

The pulley was mounted next to the clutch as it, too, was attached rigidly to the motor shaft. This pulley was first machined to reduce its weight and to make it of required size. This machining was done using carbide tip tools in MRC lathe machines. Later arc welding was used to securely attach the pulley onto the motor shaft.

7.6 Locks

There were many parts that were mounted rigidly onto the motor shaft, it was imperative that holes be drilled in them and locks put inside them to prevent any slippage during normal functioning. For the purpose of easy assembly and disassembly it was important that these locks be easy to open. Therefore for locking purposes L key screws were used after machining to make them of appropriate length.

7.7 Drive Shaft

The drive shaft fastens into a bearing in the bracket attached on the body of the motor. This bracket was custom made and machined from a block of aluminum. Machining processes here were mostly turning and facing on lathe machine and drilling using hand drills. This plate was mounted using screws onto the motor and a bearing was press fitted inside the mounting plate. This bearing was press fitted to the motor drive shaft to keep it from wobbling under normal use. As noted above, the project members and the technicians at MRC milled the keyways into the shaft using a manual mill.

7.8 Rear Motor Support

The rear support for motor was made from using 2 large C locks together. These locks were welded on the right side of the chassis and had a hole drilled between them for a screw to provide with adjustable support to the motor. The lower one of the locks was fixed in its place while the other one was free and supported only by screws. The machining was done using hand drills and arc welding from MRC.

7.9 Motor Mounting Plate

The motor mounting plate was cut by sheet metal cutter in MRC from a sheet of steel. The original size and location of the motor mounting holes were slightly off, so they were widened with a manual mill in SMME MRC’s bench fitting shop. Finally, an angle grinder was used to remove material from the bottom of the mounting plate to allow it to lay flat on the frame

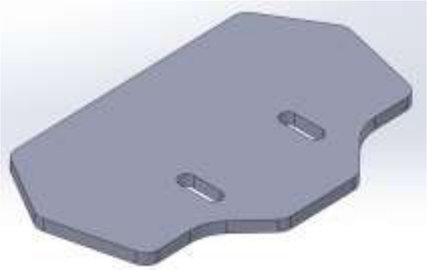


Fig 7.1: Motor mounting plate

7.10 Generator Mounting Plate

The gear mounting plate was originally cut by sheet metal cutter in MRC from a steel sheet. A hole was cut in to it to allow for bolts to pass through it and secure it to the frame. This hole was made by use of a drill tool mounted on a milling machine. Next, a drill was used to cut mounting holes for fisting the generator onto the mounting plate.

Fig 7.2: Generator Mounting Plate

7.11 Motor

The motor itself needs to be machined before it could be used for purpose of this project. First the motor shaft was machined to remove the gears which added additional frictional losses. Then it was machined to fit rigidly to the drive shaft to increase its length. This machining was done with diamond tip tools. These were not available in MRC and therefore this machining had to be done by craftsmen outside NUST.

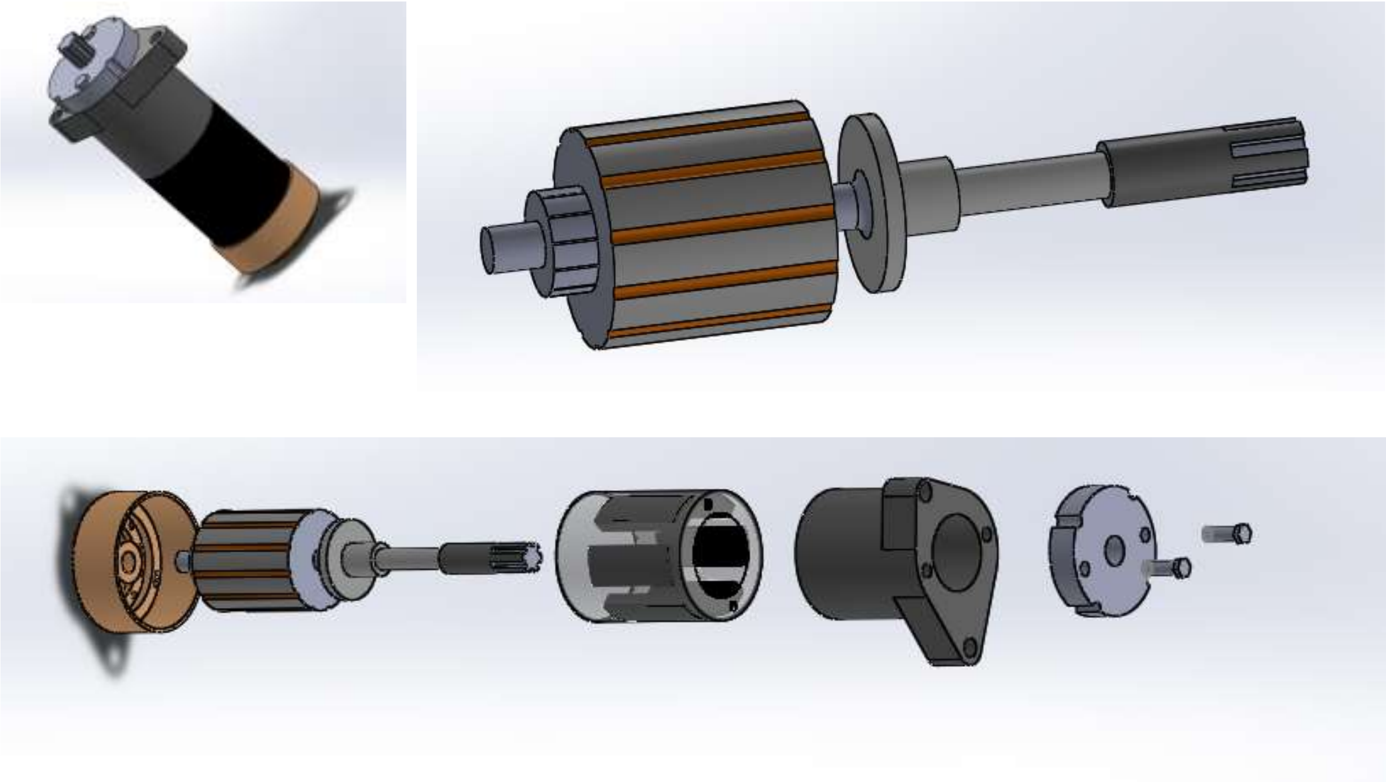


Fig 7.3, 7.4, 7.5: Motor Design

7.12 Electronics Casing

The casing for the electronics and battery covers were originally going to be cut out of a Bakelite sheet. However, it was decided to cut these parts out of ¼ inch wooden sheets as they were easily available in MRC. This design change was due to price and convenience of machining. The wood was free and easier to work with, being that it was easy to laser cut. Also, it was decided that the forces on the casings would be within tolerances, as the only loads they would be subject to consist of the weight of various light electrical circuits.

Chapter 8

Results and Conclusion

8.1 Brief Description:

The challenge set forth by this final year project team was met with a pragmatic appreciation of the project's broad scope. There were numerous facets that determined success in this final year project, and overcoming those obstacles developed the team's understanding of the multidisciplinary and deeply varied challenges inherit to this type of engineering project.

8.2 Results

An attempt to test the motorbike was made. The bike was tests on the road in front of SMME and readings were taken. Initial tests were done in MRC electrical workshop and using a Clamp meter readings of current and voltage during normal operation were used. It showed that an impulse current of 400 amperes was needed but normal running current of the motor at speed of 40 km/h was around 60 amperes. Regeneration was also tested. The results found were very promising. There following graph shows the regeneration current by the alternator at different speeds

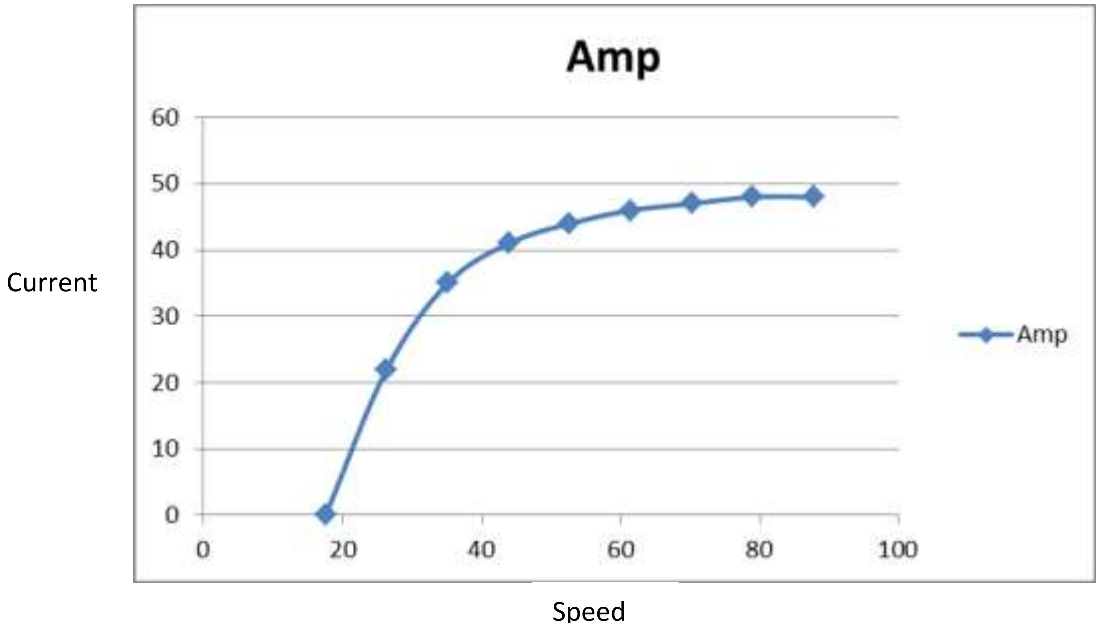


Fig 8.1: Current vs Speed

8.3 Project Limitations

Through the course of this project the team has encountered many setbacks that have led to the major difficulty in completing the objectives to the best of the group's ability. There are both external and internal obstacles that the group encountered. Listed below are all of the setbacks experienced throughout the project:

- Being limited to 12 volts power supply in our circuits
- Excessive and repetitive simulation analyses
- External and internal parts machined (lead times longer than anticipated)
- Design and alteration of the motor
- Delays in ordering and shipment of parts
- Communication

- Inadequate machining experience
- Limited funding

8.4 Project Sustainability

This project will be an ongoing effort to maximize the energy use of electric motorbikes for urban use. As a test bed, it will provide a platform for future projects to continue researching and developing a more proficient regeneration system, a lighter frame, and reduction of overall cost. Prospective students and staff interested in researching and developing methods to more effectively recover this energy should take note of this project and the progress made to establish a workable test bed for future study.

8.5 Future Work

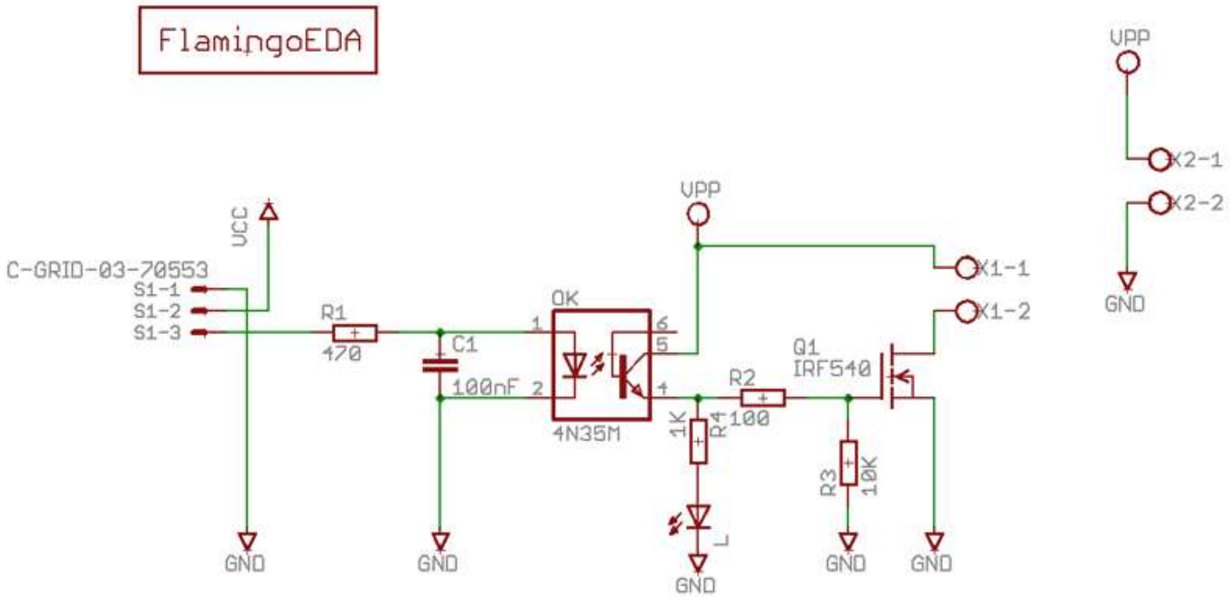
There were various technical limitations that the final year project group faced in developing this test-bed. For the groups that continue this final year project in future years, the following technical considerations may be implemented:

- More robust mounting solution for non-PCB electrical components
- Change the circuit and all electronic components to 24 volts instead of 12 volts
- Wiring harness to neaten wires
- Improved throttle
- More efficient batteries
- Better frame to mount components on
- Paint frame to avoid corrosion
- Proper wire interconnects

- Relay contacts to be rated for higher current levels
- Consider different methods of current control (e.g. IGBTS)
- Lower power dissipation through analog control systems
- Consider changing method of duty-cycle modulation to microcontroller.
- Improved battery capacity

Appendix A

MOSFET Module Driver Diagram



Appendix B

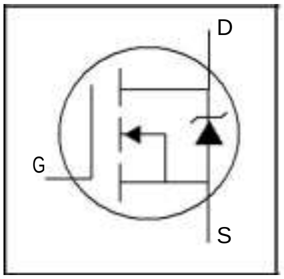
International
IOR Rectifier

PD-91279E

IRF3205

HEXFET® Power MOSFET

- Advanced Process Technology
- Ultra Low On-Resistance
- Dynamic dv/dt Rating
- 175°C Operating Temperature
- Fast Switching
- Fully Avalanche Rated



V_{DSS} = 55V

$R_{DS(on)}$ = 8.0mΩ

I_D = 110A…

Description

Advanced HEXFET® Power MOSFETs from International Rectifier utilize advanced processing techniques to achieve extremely low on-resistance per silicon area. This benefit, combined with the fast switching speed and ruggedized device design that HEXFET power MOSFETs are well known for, provides the designer with an extremely efficient and reliable device for use in a wide variety of applications.

The TO-220 package is universally preferred for all commercial-industrial applications at power dissipation levels to approximately 50 watts. The low thermal resistance and low package cost of the TO-220 contribute to its wide acceptance throughout the industry.

TO-220AB

Absolute Maximum Ratings

	Parameter	Max.	Units
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ 10V	110 …	A
I_D @ T_C = 100°C	Continuous Drain Current, V_{GS} @ 10V	80	
I_{DM}	Pulsed Drain Current •	390	
P_D @T_C = 25°C	Power Dissipation	200	W
	Linear Derating Factor	1.3	W/°C
V_{GS}	Gate-to-Source Voltage	± 20	V
I_{AR}	Avalanche Current•	62	A
E_{AR}	Repetitive Avalanche Energy•	20	mJ
dv/dt	Peak Diode Recovery dv/dt ƒ	5.0	V/ns
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to + 175	°C
	Soldering Temperature, for 10 seconds	300 (1.6mm from case)	
	Mounting torque, 6-32 or M3 srew	10 lbf•in (1.1N•m)	

Thermal Resistance

	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	——	0.75	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.50	——	
$R_{\theta JA}$	Junction-to-Ambient	——	62	

Appendix C

Financial report

Cost breakdown

- Total cost = Rs. 14400
- Fuel cost = Rs.80 per litre
- Average Bike Mileage= 60km/L

Expenses Paid		**Projected expenses**	
Motor	**Rs. 1000**	**Mounting**	**Rs. 600**
Chain	**Rs. 700**	**Electronics**	**Rs. 3200**
Sprocket	**Rs. 400**	**Batteries**	**Rs. 8500**

SR#	**Cost per kilometer**	**Estimated Mileage Per litre (With Kit)**	**Cost per kilometer(with kit)**	**Breakeven point**
1	Rs. 1.33	70 Km	Rs. 1.14	79000 Km
2	Rs. 1.33	90 Km	Rs. 0.89	34000 Km
3	Rs. 1.33	100 Km	Rs. 0.80	29300 Km

Appendix D: Operations Manual

Our prototype has reached the working state with all the systems interacting properly. Theoretically, this hybrid dive of the bike will have a maximum speed of roughly 13.4m/s (about 30mph) and a cruising speed of about 11.2m/s (about 25 mph). The idea is a short battery life with a relatively small recharge time that would allow the vehicle to be charged at any charging outlet rather quickly. This is so that the operator of the vehicle could just plug it in and be ready to ride for around 60 kilometers without regeneration after a full charge of battery.

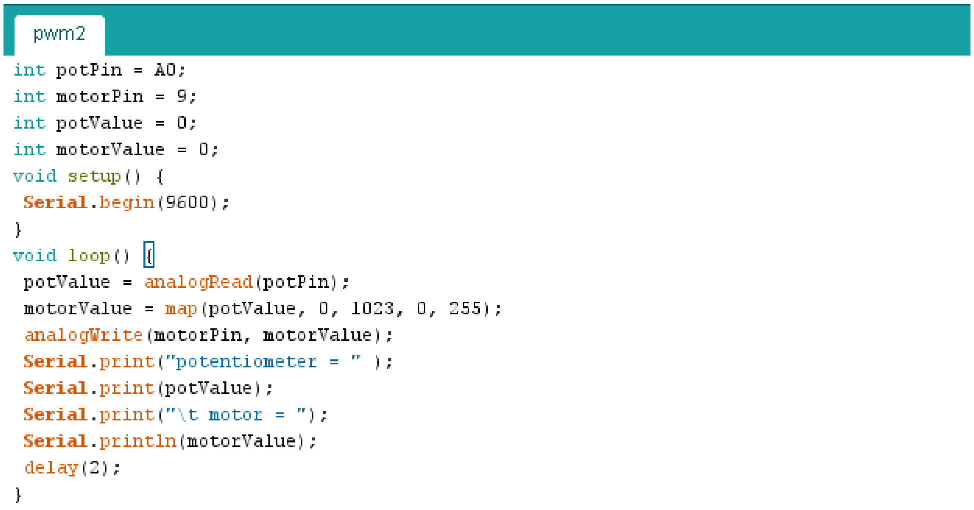
The goal of this project, of course as the title implies, is to offer a regenerative braking solution to the bike to recover some of the energy that would otherwise be lost to the brakes as heat energy. Both the control over speed and the control over this energy regeneration are governed by the position of a throttle mounted on the handlebars to the right while riding.

The motorbike is in braking whenever the clutch or the rear or front brakes are applied. A clicking sound can be heard from the relay whenever regeneration is engaged and an led on the generator goes off showing that regeneration is taking place. When the driver wants to drive the bike, he has a switch in front of him with which he can control whether to use electronic drive or mechanical drive. The regenerative braking is disengaged during electronic drive because the speed is insufficient for the regeneration to occur. The motorbike will begin capturing energy at the highest rate whenever braking is started. Further braking will engage mechanical brakes to stop the bike. Simultaneously with energy capture enabled, the motorbike will begin braking.

The circuit controlling this throttle is driven by a separate power source than the power electronics. The motor power source needs to be recharged approximately every hour on the present bike model, based on how long it’s been braking versus how long it’s been driving in motor mode. Presently the batteries are Li-Po secondary cells, therefore they are rechargeable. Even if the Li-Po cells fully deplete their charge, they still have the capability of being used in normal operation.

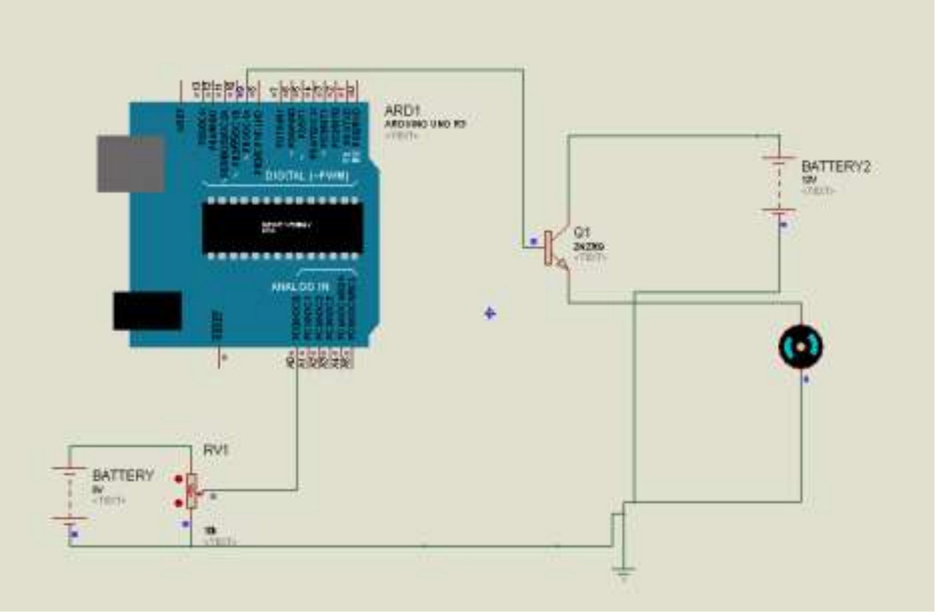
Appendix E: Circuit Code and Simulation

PWM Code



```
int potPin = A0;
int motorPin = 9;
int potValue = 0;
int motorValue = 0;
void setup() {
 Serial.begin(9600);
}
void loop() {
 potValue = analogRead(potPin);
 motorValue = map(potValue, 0, 1023, 0, 255);
 analogWrite(motorPin, motorValue);
 Serial.print("potentiometer = " );
 Serial.print(potValue);
 Serial.print("\t motor = ");
 Serial.println(motorValue);
 delay(2);
}
```

Design (ISIS)



References

[1] Alpha-Core Division of Bridgeport Magnetics Group, Inc. Amorphous C-Cores. 29 January

2014. Digital Data. 2 March 2014.

<http://www.alphacoredirect.com/contents/enus/d185_amorphous_ccores_.html>.

[2] Automobili, Rimac. "Greyp Bikes." Greyp Bikes. Greyp Bikes, 2013. Web. 10 Oct. 2013. <http://www.greyp-bikes.com>.

[3] BillC. "Transformer." 1 January 2006. Wikipedia, the free encyclopedia. Digital Image. 7 March 2014. <http://en.wikipedia.org/wiki/File:Transformer3d_col3.svg>.

[4] Bolton, Brent. “Is Regenerative Braking Useful on an Electric Bicycle?” Ecospeed LLC. 12

Oct. 2013. Web. <http://www.ecospeed.com/regenbraking.pdf>

[5] Compton, Tom. "Forces on Rider." 2001. Analytic Cycling. <http://www.analyticcycling.com/ForcesPower_Page.html>.

[6] Dillon, William E., Ph.D. "PSpice Tutorials." PSpice Tutorials. William E. Dillon, Ph.D, P.E., 17 Oct. 2007. Web. 10 Oct. 2013.

[7] Ellsworth, Timmothy J. High Efficiency Motorbike. Publication no. E-project-101112-010436. Ed. Cosme Furlong-Vazquez and Kenneth Stafford. Worcester: Worcester Polytechnic Institute, 2012. Print.

[8] Erickson, R. W. "Ch15slides.ppt." 2 March 2004. Chapter 15 Transformer Design. Digital PDF Document. 22 February 2014. <http://ecee.colorado.edu/copec/book/slides/Ch15slides.pdf>.

[9] G nen, Turan. "Chapter 6: Induction Machines." Electrical Machines with MATLAB. Boca Raton, FL: CRC, 2012. 207-66. Print.

105

[10] "Human Body Statistics." 19 June 2012. Statistic Brain. <http://www.statisticbrain.com/human-body-statistics/>.

[11] Massachusetts, Commonwealth of. Motorbike Definition and Requirements. 2013. <http://www.massrmv.com/rmv/license/7motorbike.htm>.

[12] Mohan, Ned. "Chapter 3: Switch-Mode DC-DC Converters: Switching Analysis, Topology Selection And Design." Power Electronics: A First Course. Hoboken, NJ: Wiley, 2012. 38-67. Print.

[13] “Regenerative Brakes on Ebikes”. Electricbike. 2013. Web. <http://www.electricbike.com/regenerative-brakes>.

[14] Rogers, Lennon. "Www.electricmotion.org." Www.electricmotion.org. Google Sites, 2008.

Web. 10 Oct. 2013.

[15] Umans, Stephen, Fitzgerald, A., and Kingsley, C. “Chapter 4: Introduction to Rotating Machines.” Electric Machinery. 7th Edition. New York: McGraw-Hill Higher Education, 1983. 173-244. Print.

[16] Van Der Spiegel, Jan. "SPICE - A Brief Tutorial." SPICE. University of Pennsylvania, 30 Sept. 1995. Web. 10 Oct. 2013.

[17] Van Zeghbroeck, Bart J. "PSPICE BASICS." PSPICE BASICS. University of Colorado, 1997. Web. 10 Oct. 2013.

[18] Wikimedia. American wire gauge. 25 February 2014. Web. 4 March 2014. <http://en.wikipedia.org/wiki/American_wire_gauge>.