



ASHESI

ASHESI UNIVERSITY

**MULTIPURPOSE STATIONARY EXERCISING PEDALING
SYSTEM**

CAPSTONE PROJECT

B.Sc. Electrical and Electronic Engineering

Theresa Sarudzai Chidembo

2020

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CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi
University in partial fulfilment of the requirements for the award of Bachelor
of Science degree in Electrical and Electronic Engineering.

Theresa Sarudzai Chidembo

2020

DECLARATION

I hereby declare that this capstone is the result of my original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: T. S. CHIDEMBO

Candidate's Name: THERESA SARUDZAI CHIDEMBO

Date: 11/05/2020

I hereby declare that the preparation and presentation of this capstone were supervised following the guidelines on the supervision of the capstone laid down by Ashesi University.

Supervisor's Signature:

.....

Supervisor's Name:

.....

Date:

.....

Acknowledgments

My sincere gratitude goes to Dr. Heather Beem, my capstone supervisor, who assisted me throughout my project journey. Not forgetting lecturers who taught me since freshman year. I acknowledge that the better student I am now is a result of a collective effort of my lecturers' hard work and commitment to producing world-renowned graduates. I would like to extend my sincere gratitude again to the Mastercard Foundation Scholarship (MCF), for fully funding my studies at Ashesi University. My family had been there for me in many ways, and I appreciate them too.

Abstract

Middle to low-income people in developing countries usually spend most of their time making ends meet. Therefore they do not get time to enhance their physical fitness by exercising. Moreover, frequent power cuts make them stay in the dark at home at night. In this project, an affordable home multipurpose stationary pedaling system is made. The concept of speed detection using a Hall Effect sensor, a magnet, an Arduino and a comparator is used to obtain revolutions per minute (rpm) values and time using Millis. The average maximum speed detected after five experiments is 26.57 rpm. The low-speed detection capacity is attributed to the non-robust application nature of the components used in the project. Simulation results, however, show that the minimum speed that the MatLab Simulink DC machine operating as a generator has to be supplied with is 18850 rpm input to generate power that charges a 12V lead-acid battery. As speed increases, the power produced by the generator increases. Calories burnt are determined using measured power output of the generator and frictional losses of the system converted to Joules using the standard conversion. Moreover, a charge controller that allows discharging the battery above 80% and charging at 40% of its voltage is made using circuit breakers.

Table of Contents

DECLARATION	1
Acknowledgments	2
Abstract.....	3
Chapter 1: Introduction	6
1.1 Opportunity Identified.....	6
1.2 Motivation	7
1.3 Electrical Consumption by a Typical Low Income Family	7
1.4 Related Work	7
1.5 Solution.....	12
1.6 Benefits of Solving the Problem	13
Chapter 2: Requirements.....	14
2.1 User Requirements	14
2.2 Engineering Specifications	15
Chapter 3: Design and Schematics.....	16
3.1 Deployment Diagram/ Block Diagram	16
3.2 Use Case.....	17
3.3 The Design	17
3.4 How the System Works.....	18
3.5 Components.....	19
3.41 Hall Effect Sensor	19
3.42 DC Generator	20
3.43 Pulley Belt	21
3.44 Battery	22
3.45 Charge Controller.....	23
Chapter 4: Methodology and Results	24
4.1 Speed Measurement	24
4.11 Methodology	26
4.12 Results and Discussion.....	27

4.2	Frictional Losses Determination	30
4.21	Methodology	30
4.22	Results and Discussion.....	31
Chapter 5: Simulation-Based Analysis		33
5.1	Electricity Generation	33
5.11	Methodology	34
5.12	Results and Discussion.....	35
5.2	Battery Charge Controller	40
5.21	Methodology	42
5.22	Results and Discussion.....	43
5.3	Burnt Calories Determination.....	44
5.31	Methodology	45
5.32	Results and Discussion.....	46
Chapter 6: Conclusion.....		48
6.1	Maintainability.....	48
6.2	Challenges.....	48
6.3	Future Works and Improvements.....	49
References.....		51
Appendix.....		55

Chapter 1: Introduction

Exercising for physical fitness has several benefits. They include: reduction of stress and anxiety, happy chemicals release, boosts self-esteem, a brainpower boost, sharpens memory, muscles, and bones strengthen, reduces risks of heart diseases, prevents obesity, improved blood sugar control and can guard against cancer [1]. Fitness enthusiasts understand these benefits, but those in developing countries have many limiting factors to exercise as much as they should. For instance, in Zimbabwe, in 2010, the average income was USD 100 per month [2]. The money is usually not enough for an average family to live comfortably. Adults end up taking up extra jobs to augment their meagre salaries. By the time they get home, they will be tired to do a workout. Moreover, there will be an electricity blackout. Ghana, for example, had been experiencing frequent electricity blackouts [3]. The challenges can be solved by one acquiring an affordable home multipurpose exercising pedaling system. The fact that a person has to light his/her house is an incentive to exercise. A person would have killed two birds with one stone. This paper focuses on the making of an affordable multipurpose pedaling system.

1.1 Opportunity Identified

People in underserved communities require a convenient system for exercising and at the same time generating power for their housing lighting system. The challenge they are facing is that of physical unfitness because they are always busy to exercise while making ends meet or cannot afford to pay for gym services. Moreover, an unreliable electricity supply is keeping their families in the dark during the night and there is usually an inefficient task performance.

1.2 Motivation

My motivation to work on this project is based on my personal experience. When I went back to Zimbabwe after my study abroad in Sweden, I had gained a lot of weight and my physical fitness was deteriorating. Going out for a jog was difficult because I was going to work. Unfortunately, the nation had been facing 17 hours of load shedding per day and a lot of low income to middle-income families had been using candles for lighting since solar lights prices had hiked. That is when the idea of an affordable and convenient exercising system that simultaneously generates power for bulbs started kicking around. When I came back to Ghana, I realized that power problems were the same as in Zimbabwe and I decided to research to see if the people of Berekuso in Ghana also share the same sentiments about exercising and lighting, which they did.

1.3 Electrical Consumption by a Typical Low Income Family

Table 1: Power consumption summary

Load	Power	Quantity	Operating Hours
Fluorescent	8.0	4	3
DC fan	24.0	3	18
DVD player	13	1	2
Phone	25	2	10
Television	70	1	3

1.4 Related Work

The multipurpose exercising pedaling system innovation was inspired by the early works of other scientists. What makes it unique is that it is affordable.

➤ **Energy conversion and lighting**

Francis Bienville [4] made a bicycle pedal-powered flywheel generator that generates electricity used for charging batteries. He used a flywheel since it acts as an energy reservoir by storing and supplying mechanical energy when required. The flywheel was connected to

fixed spaced magnets so that when it rotated, the current was produced. The current passed through an overcharge protection circuit when charging batteries. I find the use of a flywheel advantageous because after a person stops pedaling, it keeps rotating due to inertia. Moreover, the energy generation is cheap because magnets are cheaper than a generator set and a used bicycle from a household can be easily used and maintained [4]. I found the paper comprehensive and relevant to my project under electricity generation, excluding the magnet dynamo. However, the author would have provided details about the overcharge protection circuit.

The authors [5] made an innovation to cheaply generate electricity from cycling and a solar system attached to the bicycle. When the battery reaches 100% efficiency, a bulb can be lit for at most 28 hours. A dynamo converts mechanical to electrical energy and a solar generation unit converts solar energy to electrical. The electrical power then charges a battery. The system has many advantages. It is cheap, easy to set up and requires low maintenance. However, energy generated by solar units varies based on weather, solar unit size, efficiency, and if the solar panel becomes big, the bicycle may be imbalanced [5]. In my project, power generation from pedaling will be converted by a generator, the same way a dynamo generates electricity in this article.

Valerius, Krupar, and Schwarz [6] discuss the power management of electronic light and a tachometer system for bicycles using a dynamo. The light battery is charged by DC power after AC-DC conversion controlled by a microprocessor. Load matching is performed for the maximization of the output power. The system is simplified and focuses on a bicycle light, rather than household lights I am focusing on [6]. The good aspect of it is that there is load control that I may employ to my project since loads may differ in the same household.

An electric production system discussed in this article [7] is a hand-cranked power source. An input drive shaft is coupled to a high-speed harmonic drive system which forms the rotor of a three-phase alternator. Power is then produced as the output of the alternator to power small electric devices or charging batteries. The invention is portable, lightweight, durable, and cheap. It provides power during an emergency. Electricity generation in this patent [7] has similar working principles to the power generation of my project, apart from bicycle use.

➤ **Calorie measurement and screen display**

The writer of the article [8] outlines the measurement of calories expended by a person lifting weights. Sensors determine the displacement of the weight and a computer translates the displacement to a corresponding calorific value. At each time the cumulative quantity of calories is displayed on the screen. The system described in this patent [8] is complex. About my multipurpose pedaling system, calories burnt will be determined from power input by a person pedaling.

Patch, Li, and Gooch [9] researched an exercise data logging system that uses retrofitted weight stack equipment for data collection. Microcontrollers and off-the-shelf sensors were used to track a person's progress when exercising. The system is accurate but expensive. The motivation I drew from the article [9] was to consider using a cheap sensor because it gives relatively accurate results.

The device in the patent [10] is used to track the time to use a certain amount of energy by a person having weight problems. It was proven that the volume of gas exhaled by an individual is directly proportional to the number of calories expended. Therefore, calories expended can be found when the volume of gas exhaled is known [10]. However, the method is expensive. My system's mantra is affordability.

A new reliable and compact system for measuring the energy expended during a physical activity using a novel algorithm was made by four researchers Jang, Jung, Kang, and Kim [11]. Acceleration signals were acquired through a 15-channel whole body segment acceleration system and then the new algorithm estimates the calories expended. The disadvantage of using an accelerometer is that it lacks accurateness of measurements and is a bit expensive for a middle-income person [11].

➤ **Rotating speed measurement and screen display**

The research [12] shows that a ball-bearing triboelectric nano-generator collects rotational kinetic energy, and serves as a self-powered multifunctional sensor. The ability to obtain periodic signals of the ball based on the time difference between several cycles enables the ball-bearing to obtain rotation speed. The process of obtaining the rotary speed is a bit complex as compared to the one using a Hall Effect sensor [12].

A tachometer which measures shaft speed with the use of sine and cosine signals response to the angular position is made in this project. Two Hall Effect devices are used as electrical input and output. When the pulses are integrated, a DC output is shown which represents shaft speed. The speed measurement in this patent [13] as compared to the first one is complex.

In this paper [14], a bicycle speedometer, tachometer, and odometer devices are discussed how they can be made. A solid-state bolt-on bicycle accessory shows vehicle speed and drive-sprocket revolutions per minute. The drive upon rotation produces pulses in a coil which are received by an amplifier. They are then differentiated to trigger a multivibrator that drives a d"Arsonval meter which gives revolutions per minute tachometer reading [14]. This method of rotary speed measurement is not economic.

An activity monitoring system is made, which measures speed, calories burnt and distance traveled during a ride. The monitoring system devices are hall-effect sensor, smartphone, magnet, global positioning system, microprocessor and software for embedding the system. The method of speed measurement is cheap and easy to implement [15]. I will adopt the Hall Effect sensor method of rpm measurement.

➤ **Hall Effect Sensors**

In the book *Hall Effect sensors* by Edward Ramsden [16], a discussion about how Hall Effect was discovered, main areas of applications and advantages are done. Edward [16] tells us that the most common application of Hall Effect sensors is in proximity, position, speed, and current sensing. It is more preferable because of its small size, ruggedness, ease-of-use and low cost. Because of these advantages, the Hall Effect sensor became a good choice for my project. One disadvantage is the inaccuracy of the sensor when the environment has magnets that can interfere with the main magnetic field of interest [16].

In this invention by Sava and Machamer [17], Hall Effect elements are placed in proximity to magnets to detect the position of a joystick controller. The position of the magnet relative to the Hall Elements which would be showing the Hall Effect voltage makes up a function that is then used for position sensing. The patent [17] made me appreciate how powerful a Hall Effect sensor is in position sensing in rotary machines.

The article [18] discusses position sensing along two different axes. The linear Hall Effect sensor detects y-axis position changes and another is for the x-axis. Their assembly is used for determining the position. The patent [18] further emphasizes the dominance of Hall Effect sensors in rpm measurement, but it is not comprehensive.

In the book [19], the advantages of Magnetic sensors using Hall Effect are stated. The advantages which stand out are that Hall Effect sensors are small, inexpensive and very

common. Hall Effect voltage calculations and all related computations are listed out [19]. The advantages and disadvantages of Hall Effect sensors are coming in handy in my choice of the sensor in my rotary speed measurement.

AZoSensors [20] outlines what Hall Effect is, how the sensors are designed, their advantages and disadvantages, applications and recent developments using the sensors. The advantages are: output voltage is independent of the rate of detected field, the sensor is not affected by ambient conditions, it does not have contact with any mechanical part, it operates at a wide temperature range, and high-speed operation is possible and can measure zero speed. However, high temperatures affect the resistance of the element and it is affected by other magnets [20]. The advantages outweigh the disadvantages, so I choose a Hall Effect sensor as a sensing device for pedaling speed detection.

1.5 Solution

A stationary exercising pedaling system, which is cheap to accommodate the middle to low-income people in developing countries is the solution. The system should show on the screen the number of revolutions per minute of the rotations, the time spent pedaling and the number of calories burnt. The rotational speed measurement will be done using a tachometer. It is made of a Hall Effect sensor. The sensor is a good choice because it can easily detect a magnetic field and it is unaffected by many external physical conditions. Moreover, an alternator will convert mechanical energy to electrical energy. The electricity passes through a charge controller, which regulates the charging and discharging of a battery. The electrical energy stored in the battery is then used for house lighting.

1.6 Benefits of Solving the Problem

- The standard gym equipment is expensive, but the pedaling system will be cheap. Hence low-income people can afford one for their households.
- The system is made of easily available components, people will see the essence of some components that are thrown away as crap and start making use of them thereby reducing land pollution.
- People will be able to exercise in the comfort of their homes without worrying about going outdoors to exercise where there are high risks of getting robbed and distractions.
- Health-related problems will be reduced because of constant exercise.
- Rotational energy during pedaling will be converted to electrical energy which can be stored for lighting bulbs when there is no electricity.
- A clean source of light is used as opposed to paraffin or candles which produce fumes or can burn houses if improperly handled.
- The pedaling system will be safe and easy to use that when grown people in the household have not exercised, children can do so to produce electricity for their home lighting.

Chapter 2: Requirements

Table 2: What stakeholders gain or give to the project

Stakeholder	Project Inputs(What the project gives to stakeholders)	Project Outputs(What project gets from stakeholders)
Ashesi University Engineering faculty	A successful project	Guidance and knowledge
Low-income fitness enthusiasts	A cheap exercising system	Support in designing a viable product
Underserved communities residents	A cheap way of lighting their houses	Motivation to solve lighting problems
Ashesi Fund	A successful project	Funding

During the research, Ashesi University staff members who live in Berekuso were interviewed to understand the problems they encounter. After physical fitness and electricity issues came up, questions were asked about the product they would want to curb their problems. Their specifications can be summarised as follows:

2.1 User Requirements

- The product should be affordable
- The product should be compatible for use in a small home
- The product should show exercise progress and achievements
- The product should generate electricity for lighting
- The product should be safe for use by children

- The product should be easy to maintain
- The product should be reliable
- The product should be aesthetically appealing

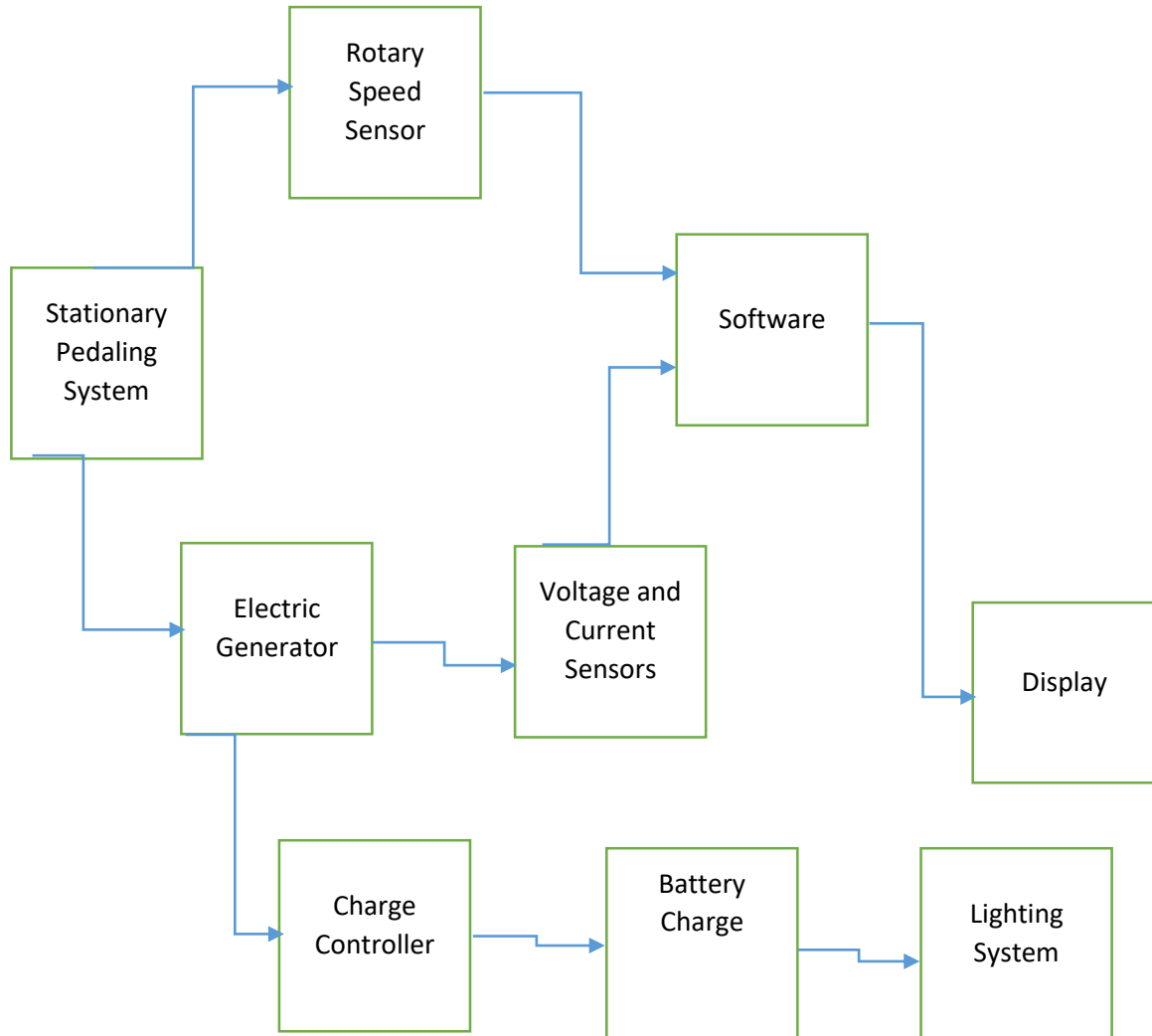
Knowing what stakeholders want gives a reference as to whether goals are achieved or not by engineers. Engineering specifications are quantifiable to make engineering work realistic. The system should have the following engineering requirements:

2.2 Engineering Specifications

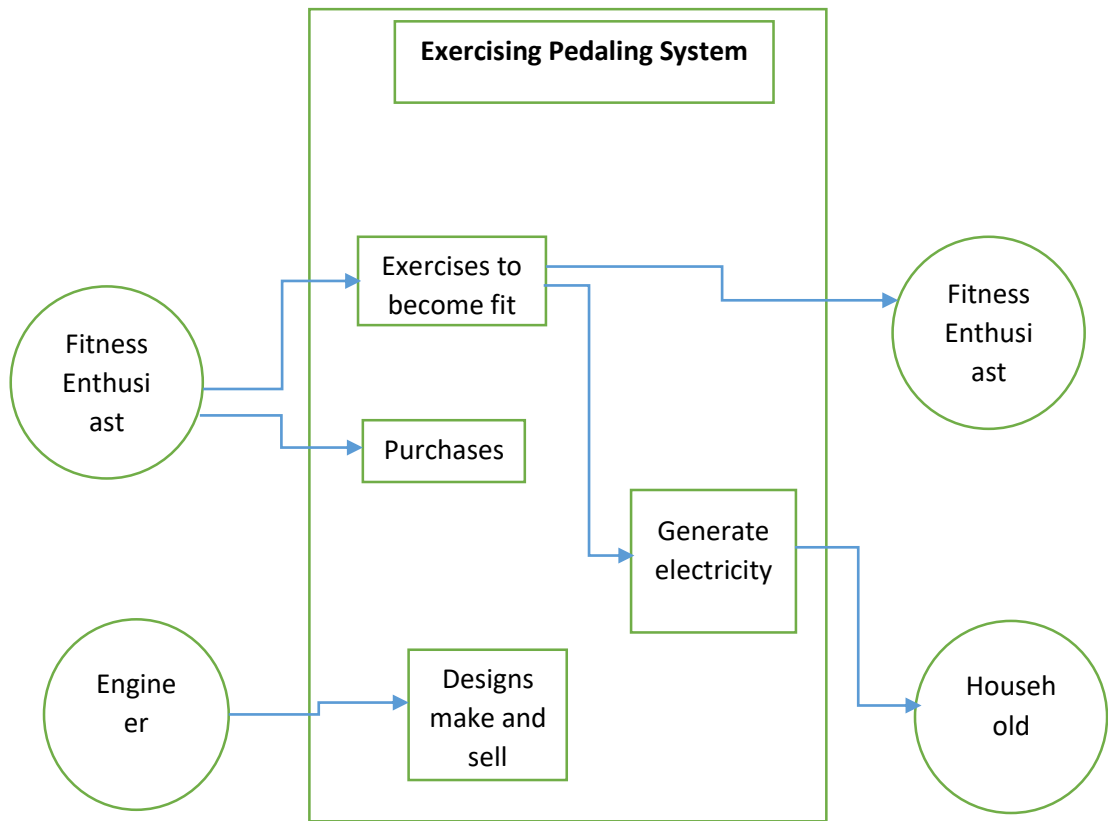
- The system should be 25-35 kilograms light
- The system should indicate the time spent pedaling, calories burnt and the number of revolutions per minute on a liquid crystal display 20*4.
- The system should generate electricity which can charge a 12Volt battery and light energy-efficient 8Watt light bulbs
- The system should take at most 10-20 minutes to install

Chapter 3: Design and Schematics

3.1 Deployment Diagram/ Block Diagram



3.2 Use Case



3.3 The Design

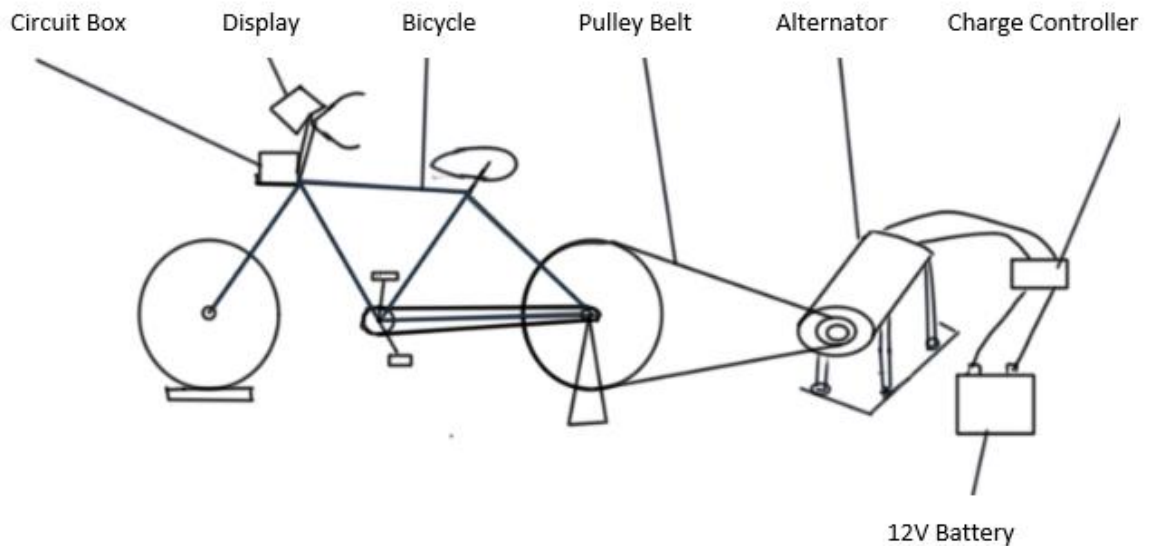


Figure 1: The multipurpose exercising pedaling system design made using SketchBook software



Figure 2: The multipurpose pedaling system design in Solid Works.

3.4 How the System Works

When a fitness enthusiast begins pedaling, rotation takes place. A magnet is coupled with a rotating part of the system, which when the magnet passes through the Hall Effect sensor, the Hall voltage value changes. It either increases or decreases based on the polarities of the magnets interacting. A comparator is used to obtain digital values (0 or 1) or (HIGH or LOW). When a magnet is detected, the comparator output is HIGH and when there is no magnet detected, the comparator output is LOW. A timer is used to measure the pedaling time and the number of cycles is determined. Therefore, rpm is calculated using the software.

For electricity generation, the mechanical energy from pedaling initiated by a person is converted to electrical energy by an alternator. To obtain the calories burnt by a person

pedaling, power input is converted to calories, using standard conversion values. The power input is obtained by using power output and system inefficiency values in an efficiency equation. Pedaling time, calories burnt and the number of revolutions per minute will be displayed on an LCD. Further, the power generated by the generator passes through a charge controller to charge a battery. The stored energy is then used to power light bulbs.

3.5 Components

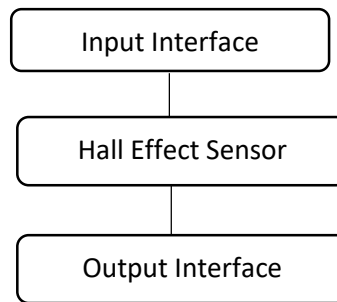
3.41 Hall Effect Sensor

When a conductor carrying current is placed in a magnetic field, a voltage perpendicular to the magnetic field and current is generated. This principle is called the Hall Effect. The magnetic field causes a force to be exerted on the current called Lorentz force. The force disrupts the current distribution. Electrons uniformly align on one side of the conductor and positive ions to the opposite, resulting in a potential difference across the output. The potential difference is called the Hall voltage. Hall voltage is small and it requires amplification for it to be usable for several applications [16].

$$V_H \propto B \times I$$

Where **B** is the flux density in Tesla and *I* is current in Amps.

A Hall sensing device needs a magnetic system that can respond to physical parameters sensed through the action of the input interface. In this project, the input interface is mechanical (the rotation of a wheel with a magnet). The magnetic field is sensed by a Hall Effect sensor that results in an electrical signal. In the sensing device used in this project, the magnetic system was integrated into the sensor chip during design. The output interface converts the electrical signal to the one an ATmega can use. The system is summarised in the figure below [20].



Reasons why the Hall Effect Sensor is used

- It does not have contact with mechanical parts, making them strong and sensitive to detect movement.
- Does not wear over time
- Can measure zero speed
- Can operate at high speed
- Can work over a wide temperature range
- Can provide highly repeatable operation
- It can produce large voltages having a semiconducting material which has small conductivity.
- Cannot be affected by dust, light, humidity, and vibrations

Disadvantages

- External magnetic fields can interfere with the sensor magnetic field
- Very high temperature affects the sensitivity of the sensor

3.42 DC Generator

A generator is a machine that converts mechanical energy into electrical energy. It works based on Faraday's law which states that when the magnetic flux linking a circuit changes,

an electromotive force is induced in the circuit proportional to the rate of change of the flux linkage. The e.m.f causes current flow given the conductor circuit is closed. The voltage in each conductor is given by:

$$e_{ind} = Bvl$$

Where B is the flux density in Tesla, l is the length in meters of the conductor in the magnetic field and v is the conductor velocity in meters per second [21].

In this project, the mechanical (rotational) energy from pedaling is converted to electrical energy by a separately excited DC generator. A separately excited DC generator has a field that is supplied by an external DC voltage source [21]. Its equivalent circuit is as shown in figure 2.

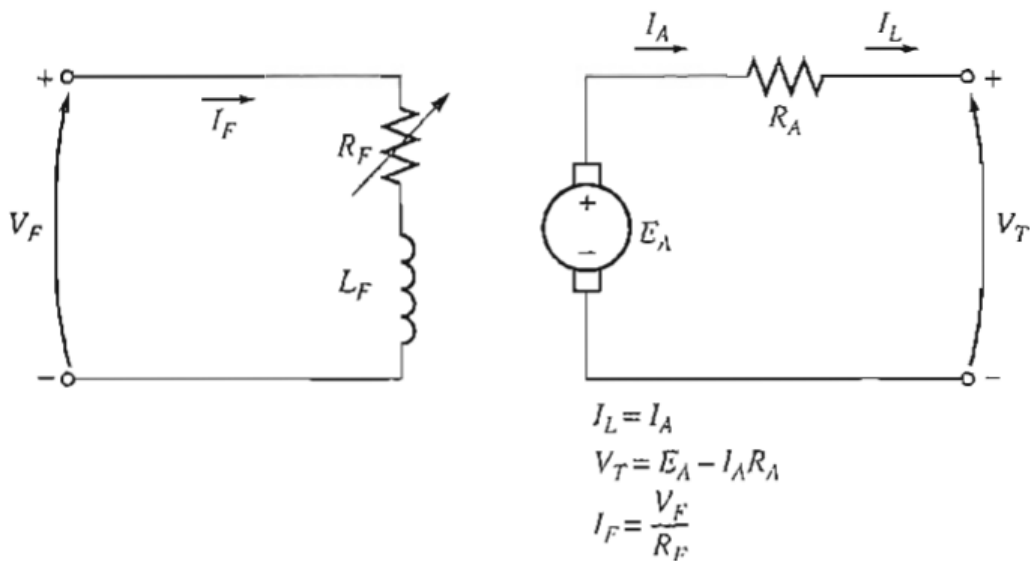
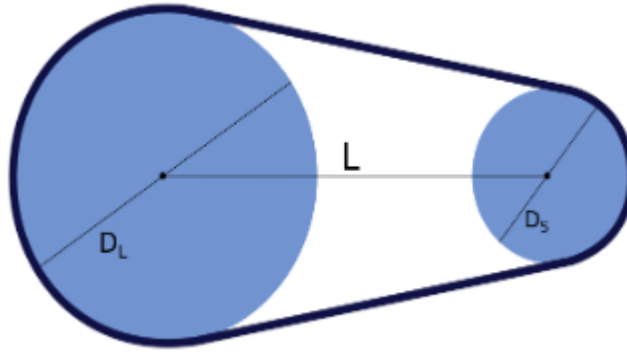


Figure 3: Equivalent circuit of a separately excited DC generator
Source: Adapted from [21]

3.43 Pulley Belt

Calculations have to be done for a pulley belt length to be correctly determined for a system. The equation is as follows:



*Figure 4: Pulley belt setup
Source: Adapted from [31]*

$d_1 =$ diameter of larger pulley

$d_2 =$ diameter of the smaller pulley

$c =$ centre distance between two pulleys

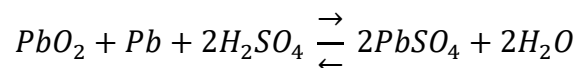
$L =$ length between centers of the two pulleys

$$L = \frac{\pi}{2}(d_1 + d_2) + 2c + \frac{(d_1 - d_2)^2}{4c}$$

The length is necessary when choosing which pulley belt to procure.

3.44 Battery

An electrical battery has electrochemical cells that convert stored chemical energy into electrical energy. In this project, a lead-acid 12 V battery is a battery of choice. The chemical reactions in the battery are as shown in the chemical equations.



\rightarrow Discharge direction

\leftarrow Charge direction

The lead-acid battery is rated 200Ah and delivers 20A of current for 10 hours when in 25°C temperature conditions [25]. The advantage of using a lead-acid battery is that it is the cheapest secondary power source, is recyclable and safe. However, it has low specific energy.

3.45 Charge Controller

A charge controller is a voltage or current regulator, which keeps batteries from overcharging. When regulation is not done, a battery may get damaged due to overcharging [22].

Chapter 4: Methodology and Results

4.1 Speed Measurement

Aim

- Speed measurement of a rotating pedaling system and determination of pedaling time.

Setup

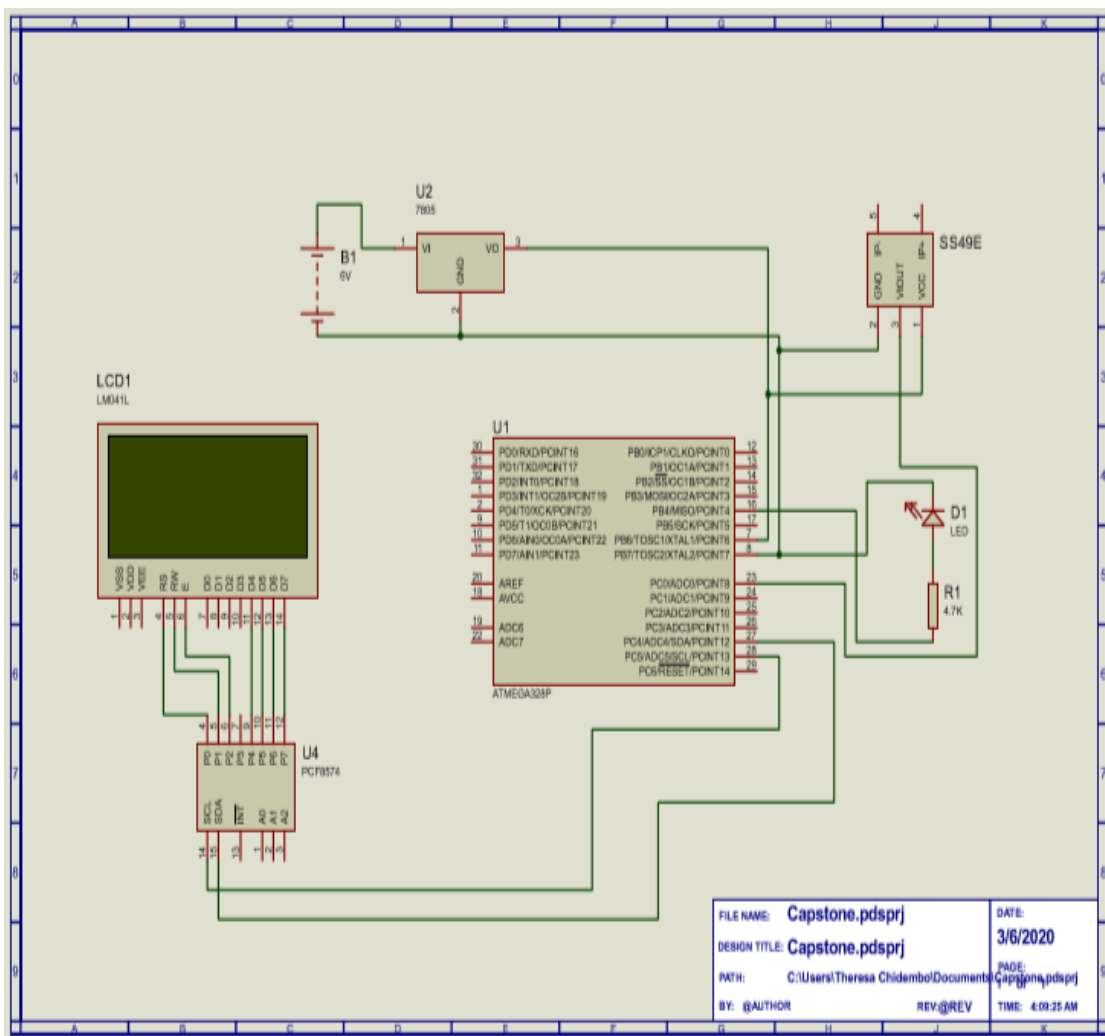


Figure 5: Speed sensor circuit design made using Proteus Software

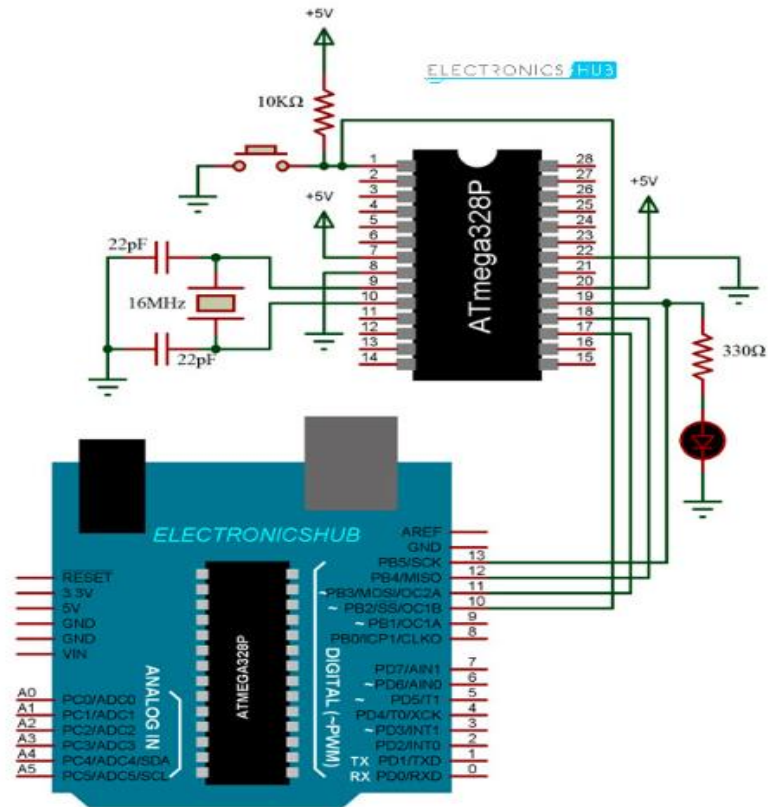


Figure 6: Circuit design of how to bootload and upload code on ATmega 328P
Source: Adapted from [34]

Apparatus

- SS49E Hall Effect sensor
- Resistors 4.7K, 10K
- Arduino UNO board
- ATmega 328P chip
- 16MHz Oscillator
- 2 22pF Capacitors
- Arduino cable
- Liquid Crystal Display 20*4
- I2C
- Bicycle

- Breadboard
- Multimeter/ Analog Discovery kit
- Arduino software
- LED
- Connecting wires

4.11 Methodology

1. Insert a Hall Effect sensor on a breadboard or printed circuit board.
2. Connect the Hall Effect sensor VCC to 5V, GND to GND and OUT to A0 on the Arduino board.
3. Measure the Hall voltage when the Hall Effect sensor detects a magnet and not.
4. Insert an LED on the breadboard, the positive leg connected to 14.7K resistors and a negative leg to GND.
5. Connect an LED through resistor connection as in step 3 to digital pin 10 of the Arduino board.
6. Connect i2C to LCD 20*4 display.
7. Connect VCC to 5V, GND to GND, SDA to digital pin 20 and SCL to digital pin 21 of the Arduino board.
8. Write a comparator code in Arduino and detect when the Hall sensor output is HIGH (1) and LOW (0) and then a cycle count.
9. Use a timer to determine the cycling time.
10. Determine the number of revolutions per minute by dividing the number of cycles by the time elapsed.
11. Connect the Arduino board to the computer using an Arduino cable.
12. Compile the code and load it to display the rpm value and the total pedaling time on the LCD 20*4.

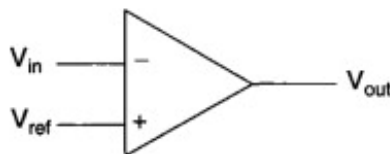
13. Boot load and upload the code to ATmega328P making the connections as shown in figure 5 so that a small and simple chip is used throughout the project.
14. Attach a magnet to the rotating part of the pedaling system.
15. The magnet should pass near the Hall Effect sensor (within 10 centimeters).
16. Begin pedaling.
17. Repeat the experiment five times at 1-minute intervals and record the maximum speed the system can detect.

4.12 Results and Discussion

NB: An Arduino mega 2560 board was used during the testing phase. Arduino UNO would have been the best when deploying the project because an ATmega chip can be inserted on the board. However, both Arduino UNO and an oscillator were unavailable the time school paused because of COVID-19. The final connections would have been like the ones shown in figure 5. The experiment was therefore conducted using available resources, see figure 8 used in the testing phase and step 13 of methodology was skipped.

Table 3: Hall voltage results

Maximum Hall Voltage with no magnet	2.35V
Maximum Hall Voltage with a magnet	2.50V



*Figure 7: Voltage Comparator
Source: Adapted from [24]*

The magnetic field from a magnet is sensed by a Hall Effect sensor that results in an electrical signal. That explains why the voltage when the magnet is present is higher than when the magnet is absent, that is out of the 10-centimeter range. Knowing the two values leads to the concept of comparators. A comparator is an analog-to-digital converter. It compares the values of two voltages and produces a digital output [24]. In this experiment, the reference voltage which corresponds to a sensor value of 500 is between 2.35V and 2.5V. When the magnet is brought closer to the Hall Effect sensor, the sensor value becomes more than 500. The corresponding voltages produce a High (1) and an LED turns on. When the magnet goes outside the range of the sensor, the sensor value falls below 500. The corresponding voltages produce a Low (0) and an LED remains off. When a 0, 1 and 0 are detected, the counter counts it as a cycle and they are counted incrementally. The total number of cycles is divided by the total time in minutes elapsed when pedaling to get the number of revolutions per minute (rpm).

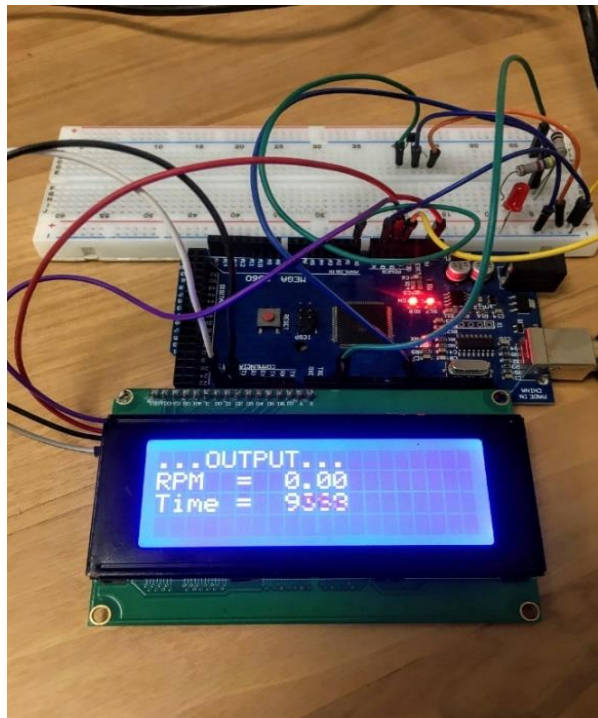


Figure 8: *Circuit, Arduino and LCD connections, displaying RPM and time in milliseconds*

The RPM and time in milliseconds values are displayed on the LCD as shown in Figure 8. Millis is used for determining the time, which starts the moment the system is turned on. The default time unit is milliseconds. The assumption is that when the system turns on, a person would have begun a pedaling session.

Table 4: Maximum speed experimental results

Experiment	Maximum Speed Recorded (RPM)
1	25.05
2	27.00
3	27.40
4	26.27
5	27.13
Average	26.57

When the experiment is conducted five times at a one-minute interval, the results came up as shown in table 4 above. The average of the maximum speeds of the pedaling system is 26.57 rpm. The maximum speed measurement capacity of the system is too small because a person can pedal at a higher speed and the system may fail to record it. The reason for the low maximum speed detection could be a low capacity of components being used to handle the project that is a little bit robust. Arduino is not usually used for robust applications for example industrial applications. It does not have a lot of extensive inputs and outputs, making Programmable Logic Controllers (PLCs) the best choice in industrial applications. If it has to be used, it is for data collection [32]. Moreover, for rotational speed sensing Rotational Speed Sensors KMI15/16 and some other effective sensors are used in automotive and industrial applications other than Hall Effect sensors [33].

4.2 Frictional Losses Determination

Aim

To determine the frictional losses of a pedaling system on the most frictional parts

Assumptions

- There is no temperature loss to the surroundings
- The mass of the total frictional parts of the bicycle is the same as that of a rim of the bicycle

Apparatus

- Temperature probe
- Multimeter
- Labquest
- Balance
- Pedaling system

4.21 Methodology

1. Measure the initial temperature of the most frictional parts of the pedaling system using a temperature probe whose specifications are:
 - Temperature range: -40 to 135°C
 - Accuracy: $\pm 0.2^{\circ}\text{C}$ at 0°C and $\pm 0.5^{\circ}\text{C}$ at 100°C
 - Response time: 90 seconds in still air
2. Pedal the system for 10 minutes and measure the temperature at the same points measured initially
3. Repeat step 2 for eight more steps and record the temperature results
4. Determine the change in temperature

5. Using $Q = mc\Delta T$, calculate the heat lost through friction and then convert it to power using standard values.

4.22 Results and Discussion

Frictional losses

Table 5: Temperature results

Time (Minutes)	Temperature (Degrees Celsius, °C)	Temperature Change (Degrees Celsius, °C)
0	26.7	0
10	27.5	0.8
20	28.2	0.7
30	28.9	0.7
40	28.5	-0.4
50	28.3	-0.2
60	29.0	0.7
70	29.5	0.5
80	29.5	0

Table 6: Quantitative results for energy calculation

Average Change in Temperature (Degrees Celsius, °C)	0.31
Mass of Frictional Parts (Kg)	1.14
Specific heat of aluminum (J/Kg.K)	921.096

$$Q = mc\Delta\theta$$

Q – Heat Energy (Joules)

m - Mass of substance (Kg)

C – Specific heat (J/Kg.K)

$\Delta\theta$ – Change in temperature (K)

$$Q = 1.14 \times 921.096 \times 0.31 = 0.3255KJ$$

Using standard conversion values [23],

$$1KWh = 36 \times 10^5J$$

$$0.3255KJ = 9.042 \times 10^{-5}KWh$$

$$P_{friction} = 9.042 \times 10^{-5} \times 3600 = 0.3255KW$$

Friction is the resistance to motion of a moving object relative to another. The energy of motion is converted to heat. The interaction of two bodies causes wear and tear. Lubricants are therefore used to reduce it. The pedaling system used in this project was lubricated first before conducting the frictional losses experiment.

Chapter 5: Simulation-Based Analysis

5.1 Electricity Generation

Aim

- To convert mechanical energy from the exercising pedaling system to electrical energy using a DC machine in MatLab Simulink software.
- To determine the effect of increasing mechanical speed on the generator current, voltage and power outputs in MatLab Simulink software.

Setup

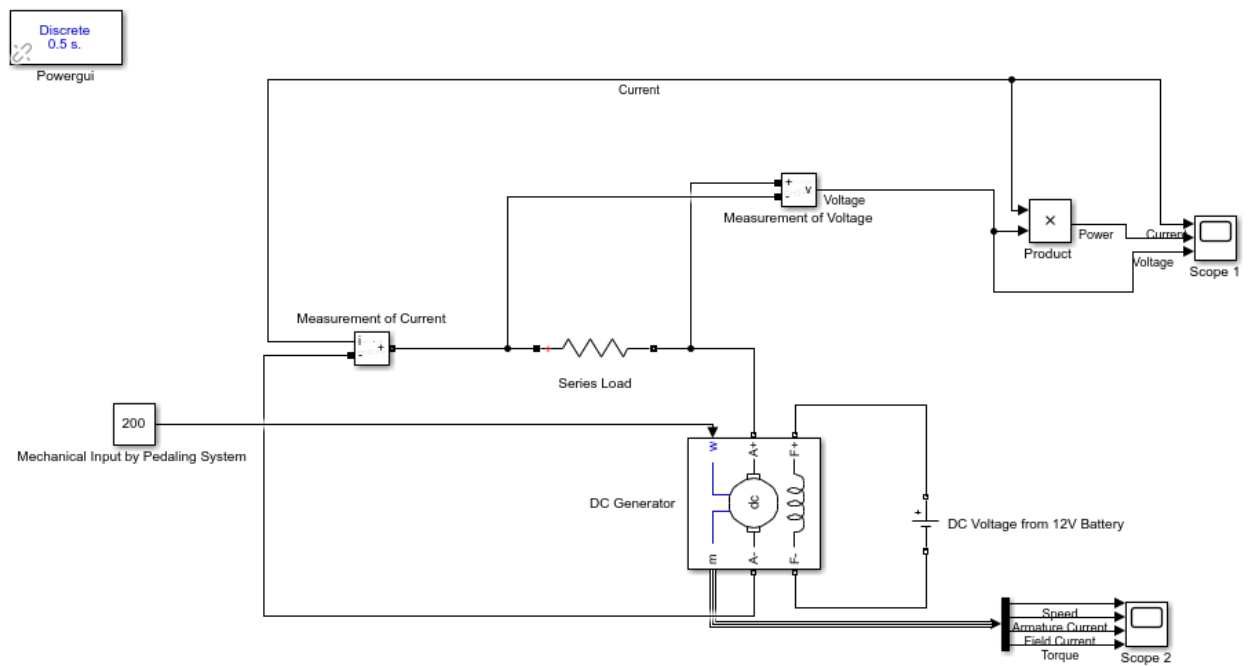


Figure 9: DC generator model in MatLab Simulink

Table 7: Simulink blocks description

Component	Description
Powergui	Used to simulate any Simulink electrical model from Simscape

DC machine	Used to implement permanent magnet and wound-field DC machine
Current measurement	Used to measure current in the circuit
Voltage measurement	Used to measure voltage in the circuit
Constant block	Used to generate constant values
Series RLC Load	Used to implement linear RLC series load
DC voltage source	Used to supply constant voltage
Product	Used to multiply and divide scalars and non-scalars
Demux	Used to obtain elements of an input vector and produce separate outputs
Scope	Used to display generated results

5.11 Methodology

1. Open MatLab software.
2. Go to 'Home', click 'New' drop-down menu and select the 'Simulink model'.
3. Select the 'Blank Model' and name the Simulink file.
4. Click on 'Library Browser' and type in the names of the components mentioned in the table above one after the other and drag them to the file.
5. Connect them as shown in figure 6.
6. Rename the components based on their essence to the project.
7. Change the parameters of the components after double-clicking on them as follows:
 - DC machine's mechanical input to speed and field type to wound.

- Constant block's constant value when the mechanical input of the DC machine is speed should be a positive number.
 - DC voltage's source to an amplitude of 12V.
 - Demux's number of outputs to 4
 - Scope 2's number of signal inputs to 4
 - Scope 1's number of signal inputs to 3
 - Series RLC Load's nominal voltage to 12 and C and L to 0
 - Powergui to discrete and 0.5 seconds
 - Stop time to 1000
8. For each execution, enter values 0 to 1000 at 100 intervals in the constant block.
 9. Click 'Run' and after execution, double click scope 1 and 2 to see the results.
 10. Record the results.

5.12 Results and Discussion

The DC machine rotor accelerates when torque is applied in the same direction as that of motion. When speed increases, internal voltage increases exceeding the supply voltage of the DC machine. Therefore, the current begins to flow into the battery charging it. An induced torque in the opposite direction of motion is caused by the current [21]. The simulation results show this theory as the induced torque values are negative see table below. The armature current of the DC machine is negative too as shown in figure 10. The DC machine is, therefore, acting as a generator.

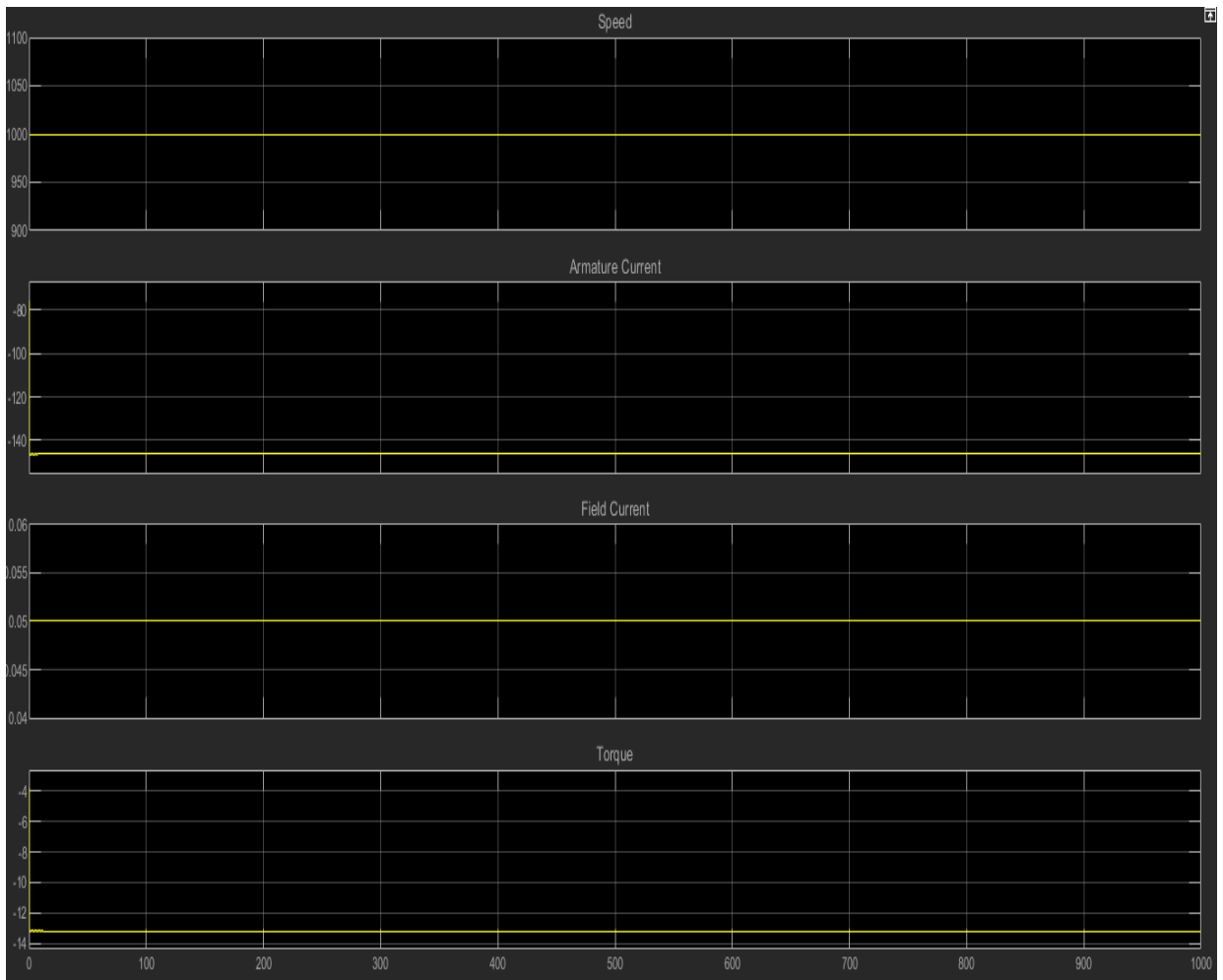


Figure 10: Parameters of the DC machine at the speed of 1000 rad/s

Table 8: DC generator inputs and output results

Speed (rad/s)	Speed (rpm)	Current (A)	Voltage (V)	Power (W)	Torque (N.m)
0	0	0	0	0	0
100	9425	15	0.21	3.1	-1.3
200	18850	29	0.425	12.8	-2.75
300	28274	44	0.65	27.5	-4
400	37699	59	0.85	49	-6
500	47123	75	1.05	78	-7
600	56549	88	1.3	110	-8

700	65973	104	1.5	150	-9
800	75398	118	1.7	200	-11
900	84823	132	1.9	250	-12
1000	94248	150	2.1	320	-13

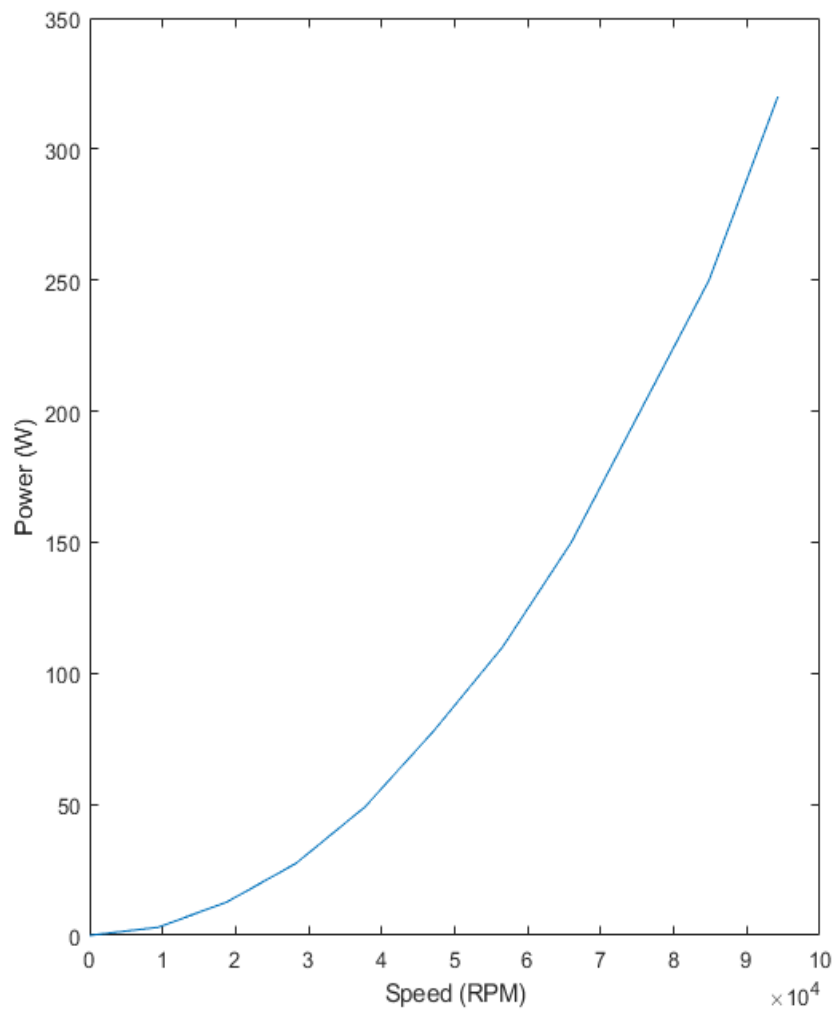


Figure 11: Power –Speed graph

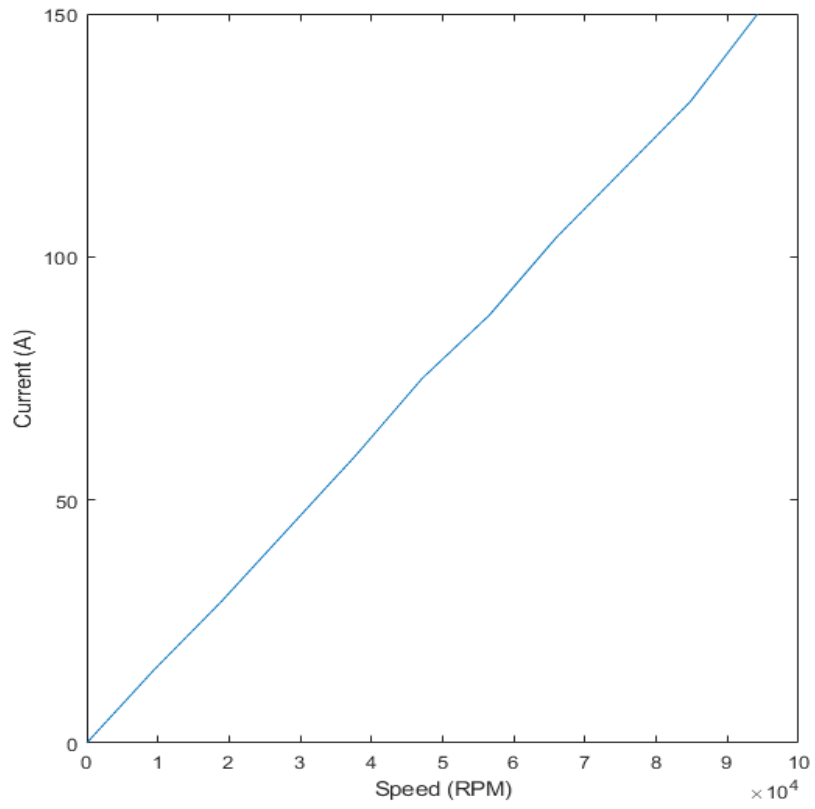


Figure 12: Current – Speed graph

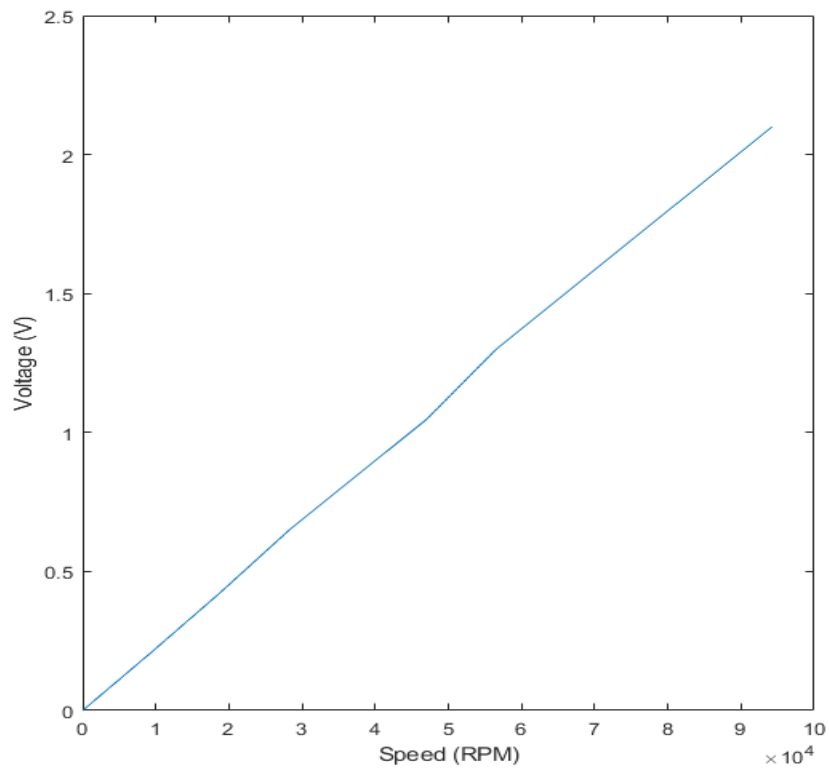


Figure 13: Voltage – Speed graph

$$E_A = K\phi\omega$$

As speed (ω) increases, internally generated voltage (E_A) also increases as seen in the equation above. Armature current, I_A increases by small values as compared to E_A . Armature resistance R_A remains constant. Therefore, the terminal voltage according to the equation $V_T = E_A - I_A R_A$ increases. The power output of the separately excited DC generator is therefore obtained by $P = V_T I_A$ [21]. The simulation results validate the theory that as the speed of the mechanical input increases, current, voltage and power from the generator increase too [25] [27] [28] and [29]. The Simulink results from scope 1 as shown in table 8 above show that as speed increases, the current, voltage across the battery and power output also increase.

On the other hand, comparing simulation rpm values to section 4.1 experimental results, there is a large gap. If simulation in Simulink is done using the equivalent rad/s values of the results in the range of zero and 26.57 rpm, the power output of the DC machine will be very low to charge a 12V lead-acid battery. The results of the simulation using 26.57 rpm converted to rad/s are shown in figure 14 below. The power output is 0.0024W.

However, the DC machine in Simulink does not have the changeable parameters to alter its voltage capacity. According to Chapman [21], the parameters which determine the output voltage of a generator are:

- i. The flux
- ii. Speed of rotation
- iii. The make-up of the machine

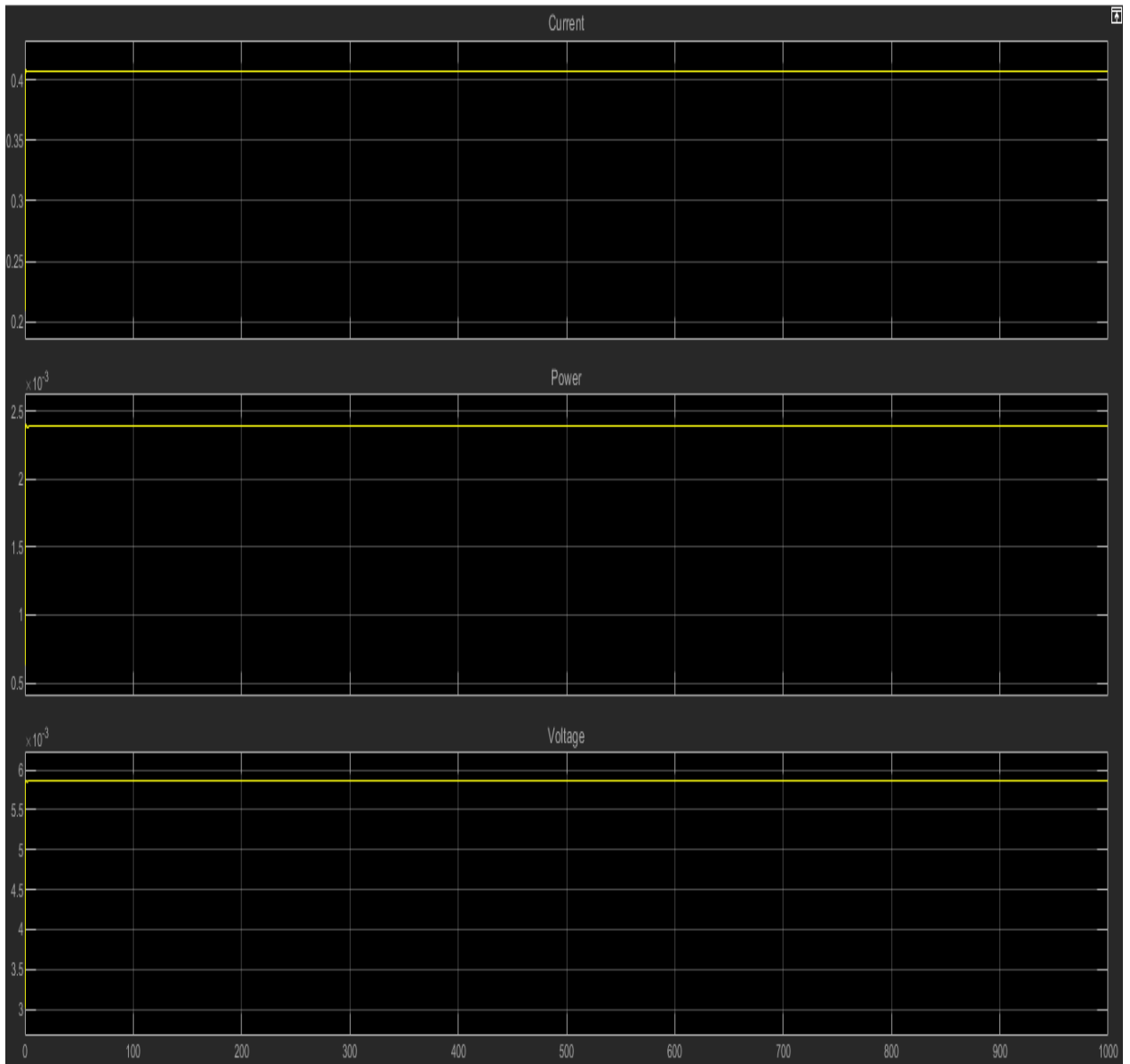


Figure 14: Simulation results when using 26.57 rpm (2.78 rad/s) as input to the DC machine

5.2 Battery Charge Controller

Aim

- To make a charge controller that avoids over drainage of the battery using MatLab Simulink

Setup

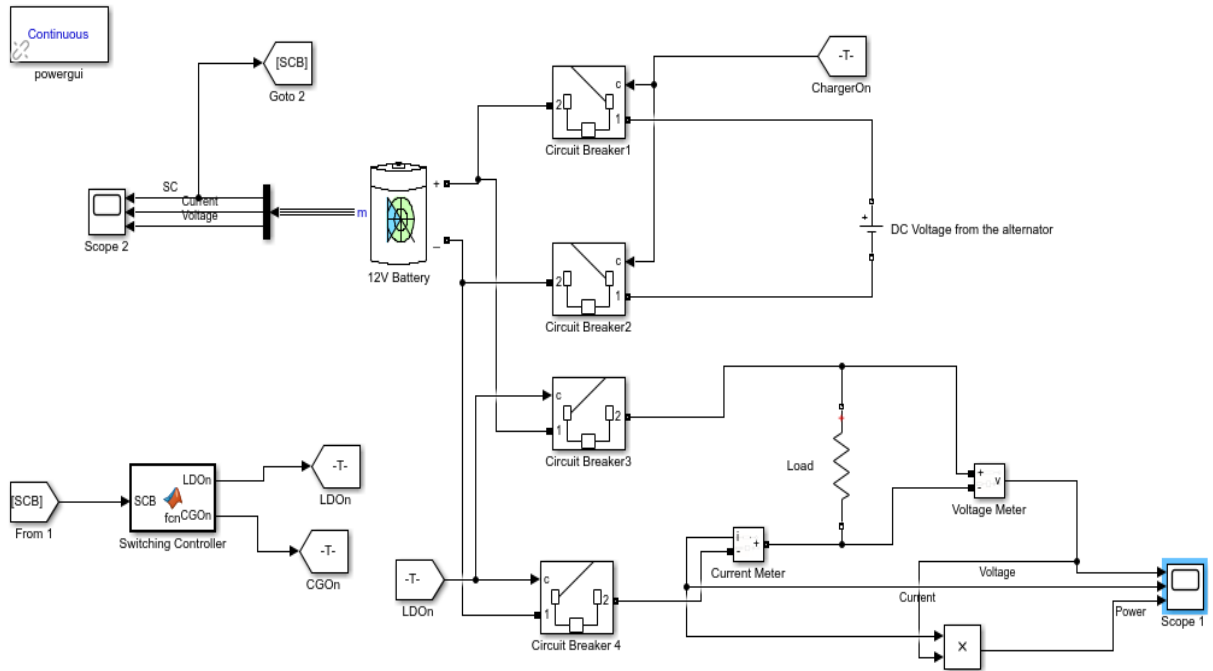


Figure 15: Battery charge controller model in MatLab Simulink

Table 9: Simulink block descriptions

Component	Description
Powergui	Used to simulate any Simulink electrical model from Simscape
Circuit breaker	Used to implement circuit breaker opening when current is zero at the crossing
Current measurement	Used to measure current in the circuit
Voltage measurement	Used to measure voltage in the circuit
Goto	Used to pass block input from From block
Series RLC Load	Used to implement linear RLC series load
DC voltage source	Used to supply constant voltage

Product	Used to multiply and divide scalars and non-scalars
Demux	Used to obtain elements of an input vector and produce separate outputs
Scope	Used to display generated results
MatLab Function	Used to interface code and block
Battery	Used to implement rechargeable battery
From	Used to accept Goto block input

5.21 Methodology

1. Open MatLab software.
2. Go to 'Home', click 'New' drop-down menu and select the 'Simulink model'.
3. Select the 'Blank Model' and name the Simulink file.
4. Click on 'Library Browser' and type in the names of the components mentioned in the table above one after the other and drag them to the file.
5. Connect them as shown in figure 8.
6. Rename the components based on their essence to the simulation.
7. Change the parameters of the components after double-clicking on them as follows:
 - Powergui to continuous
 - DC voltage source's amplitude voltage to 16V
 - Series RLC Load's nominal voltage to 5.6V, active power of 32W and C and L to 0
 - Battery's nominal voltage to 12V, the initial state of charge to 80% and type to Lead-Acid
 - Stop time to 1000

- MatLab Function code:

```
function [LDOn, CGOn] = fcn(SCB)
    LDOn=1;
    CGOn=0;
    if (SCB>=80)
        LDOn=1;
        CGOn=0;
    elseif (SCB<40)
        LDOn=0;
        CGOn=1;
    end
```

8. Click 'Run' and double-tap scope 2 to observe the battery behavior when it is being charged and is charging.

9. Record the results.

5.22 Results and Discussion

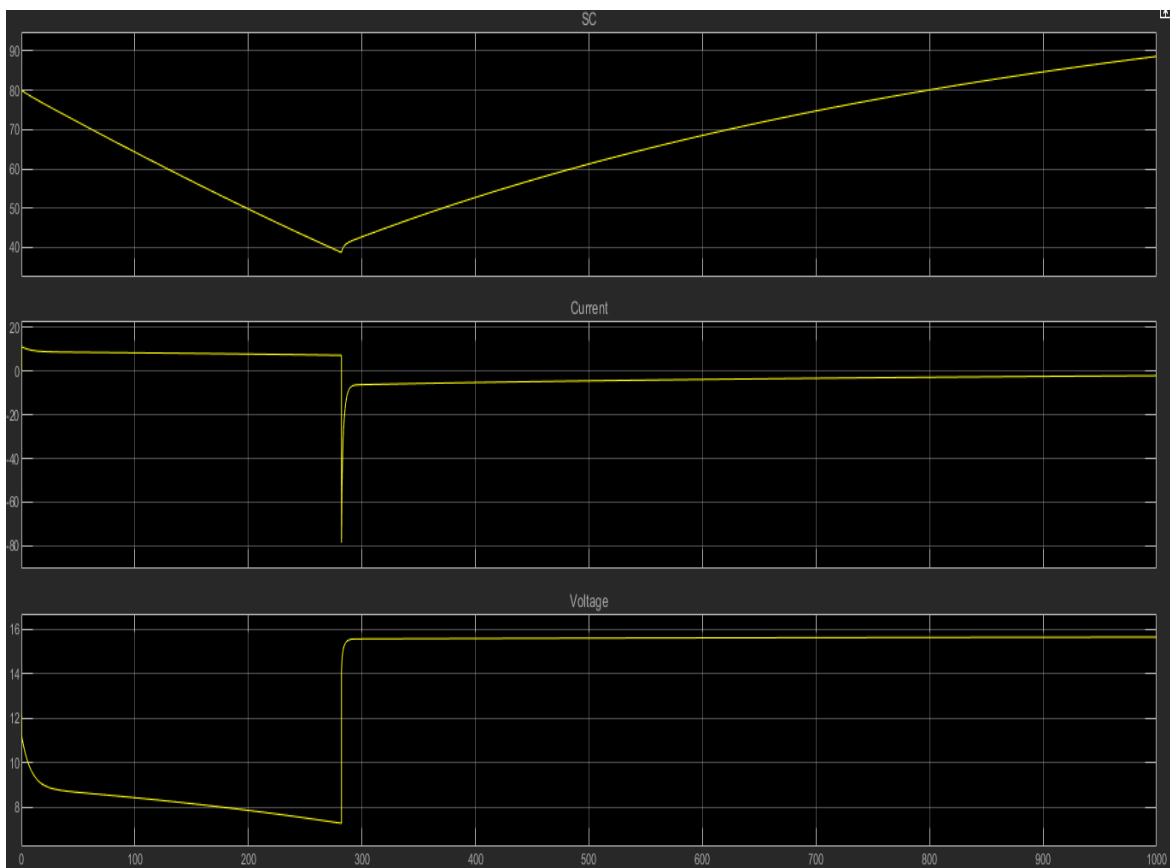


Figure 16: Battery parameters in Simulink

The battery gets charged by the DC generator power output at a voltage higher than the nominal voltage of the battery. Lead-acid batteries require at least 2.1V per cell to produce

a voltage. The larger the battery charging voltage, the lesser the time to charge it [30]. When the state of charge (SC) of the battery is at least 80%, it begins to charge the load. 80% is chosen because discharging a lead-acid battery below that percentage will damage it [30]. As soon as SC of battery is 40%, the battery is disconnected from the load by the circuit breakers and it begins to charge from the DC generator. 40% is to ensure that the battery cells remain with some voltage before they are recharged. From the SC plot in figure 16, the battery supplies power to the load from SC = 80 until SC = 40 for approximately 290 seconds. The graph shows a rise at SC = 40, meaning the battery begins to charge. At 290 seconds, current values drop to negative from 10A. It means that the current is flowing into the battery. Moreover, the battery voltage begins at 12V and drops to almost 6V. At 290 seconds, the voltage rises and stabilizes at almost 15.5V. However, 15.5V is a voltage overshoot and can cause battery damage.

5.3 Burnt Calories Determination

Aim

- To determine the number of calories burnt when pedaling

Assumption

- The power loss only considered is frictional power losses. Stray, core and copper losses are assumed to be zero.

Setup

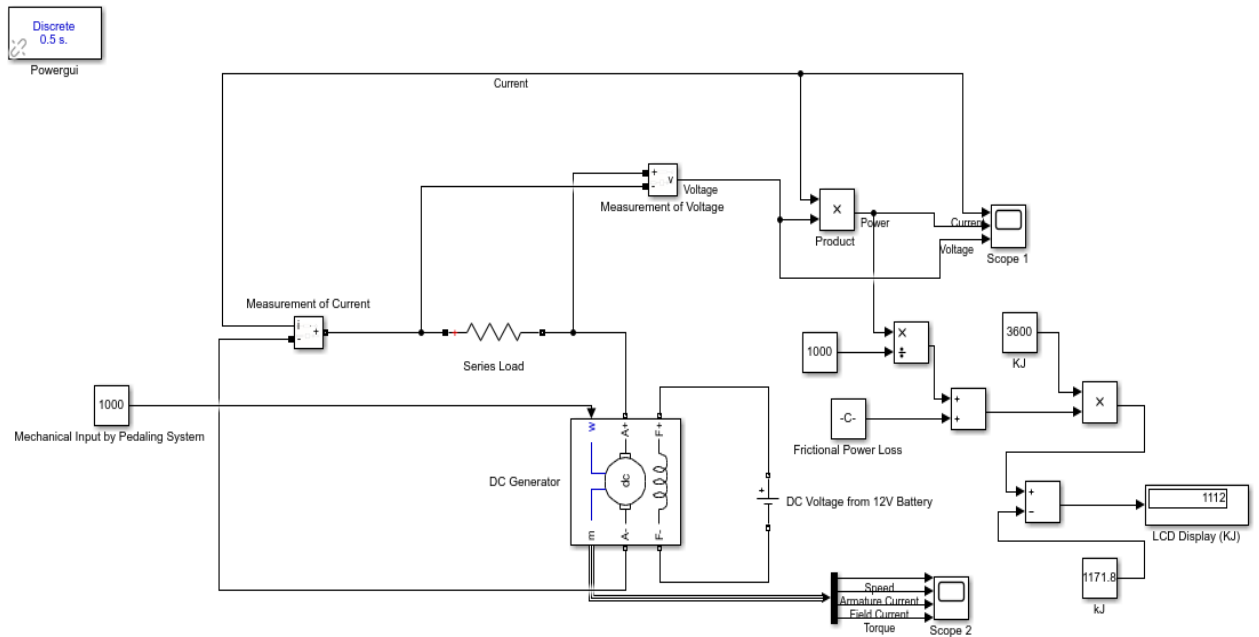


Figure 17: DC generator model including calorie determination

5.31 Methodology

1. Connect the components as in simulation 5.1 for electricity generation.
2. Connect the generator output power to a divider and divide it by 1000 to convert from Watt to kilowatt.
3. Add frictional power loss obtained in experiment 4.2 of chapter 4 and the output power from the divider to obtain power input using an adder.
4. Multiply the power input from the adder with constant 3600KJ using a product block.
5. Subtract the constant value obtained when the system is at rest from the calorie value obtained in step 4 using a sum block.
6. Show the results on the display in kilo Joules.

5.32 Results and Discussion

Table 10: Simulink results for calories burnt by a pedaling person

Speed (rad/s)	Speed (rpm)	Calories Burnt (KJ)
0	0	0
100	9425	11.2
200	18850	44.5
300	28274	100.1
400	37699	178.0
500	47123	278.1
600	56549	400.5
700	65973	545.1
800	75398	711.9
900	84823	901.0
1000	94248	1112.0

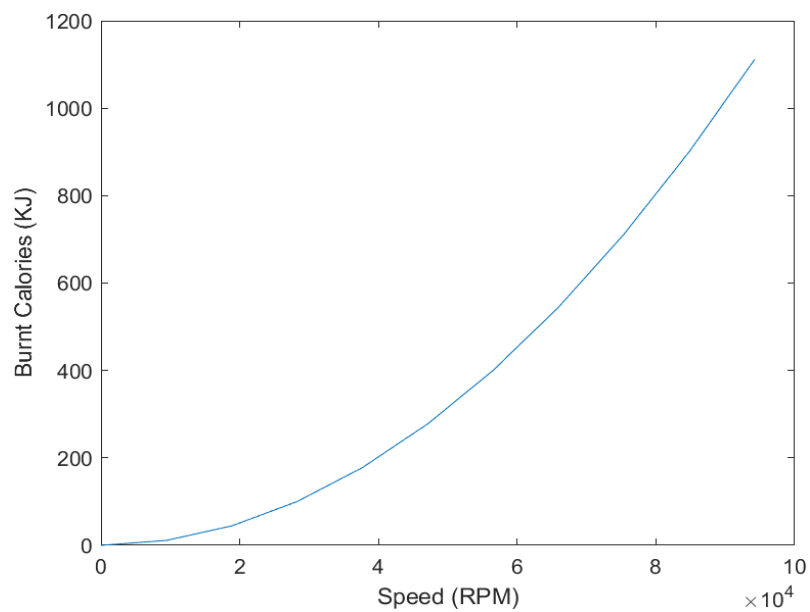


Figure 18: Burnt Calories – Speed graph

When the output voltage and current of the generator are obtained, power output is also determined by the product of voltage and current [21]. Therefore, when the power output is summed with the frictional power losses, power input is obtained. Assuming that all other losses are zero. The equation below shows the relationship

$$\textit{Power Input} = \textit{Power Output} + \textit{Frictional Losses}$$

Power input is assumed to be the equivalent power produced by the person pedaling. To convert from kilowatt to mega Joules, the standard conversion is used.

$$1KWh = 3600KJ$$

The number of calories burnt by a person pedaling increases as the person increases the speed as shown in table 10 of results obtained during the simulation. However, the system gets results when it is at rest, which is not supposed to be the case. The calorie value at rest is 1171.8 KJ. Subtracting the constant value from all the calorie values results in the actual calorie values.

Chapter 6: Conclusion

6.1 Maintainability

- Batteries do not require frequent maintenance. But when it has to be done, trained personnel have to be consulted for equalization of charges, watering of battery cells and checks on cell voltage and specific gravity. The owner of the system can be constantly wiping out dust and any form of dirt.
- Frictional parts should be constantly lubricated.
- The pedaling system should be kept under room temperatures to avoid any operations which are affected by high temperatures such as batteries and the Hall Effect sensor.
- The system should be kept away from water to avoid rusting of metal parts.
- Magnets should not be placed around the system, else it will distort the RPM results.

6.2 Challenges

1. COVID-19 pandemic affected the procurement of project components in time because trade with suppliers was stopped to avoid the spread of the virus. Therefore, the DC generator had not yet arrived when schools paused thereby affecting physical experimentation of any part of the project which relies on it.
2. The project could not be deployed to a compatible system because schools paused while the project was in the physical testing phase.
3. Resorting to simulations for demonstrating how the project works as an alternative was difficult. To implement the whole system at once takes a lot of work to make the system perfect.
4. A bicycle with multiple geared cycles can attain high speed in a short space of time.

5. Maintaining the same speed when pedaling is impractical, therefore the output voltage varies.
6. An alternator requires initial power to excite its magnetic field. The battery does this, so the alternator cannot work without the battery
7. The accuracy of the speed detection circuitry is low, therefore the system does not detect the magnet at high speeds.
8. Simulation results show that an exerciser should be pedaling at an RPM at least 18850 to begin charging the battery. The speed is extremely high to be produced by a person pedaling in a minute.
9. The MatLab Simulink DC machine when operating as a generator does not mimic an actual at least 14V DC generator that would have been used in the project since it does not have options to change voltage capacity. This produces a large gap between experimental and simulation results.
10. Having to move from school to our respective homes affected project performance in many ways:
 - Research became difficult because at home there is limited and slow internet connectivity.
 - Physical interaction with instructors and colleagues had been the norm. Having to adjust to seeking help virtually did not yield the same results as physical interaction.
 - At home there are a lot of distractions, focusing on doing the project and other courses had been hard.
 - The impact of the pandemic caused panic and emotional instability.

6.3 Future Works and Improvements

1. Project components should be procured a semester before the final semester, this is to avoid risks of not getting components due to unforeseen circumstances.

2. A permanent magnet generator could be used for instant power supply.
3. Power generation can be improved by using two rear wheels when generating electricity because there is a lot of power losses in the current system.
4. Conducting all experiments physically and collecting data for accurate analysis.

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Appendix

Arduino Code

```
volatile int sensorValue;

const byte ledPin = 10;

// Setup for LCD i2c and Libraries

#include <Wire.h> // Library for I2C communication

#include <LiquidCrystal_I2C.h> // Library for LCD

LiquidCrystal_I2C lcd = LiquidCrystal_I2C(0x27, 20, 4); // Change to (0x27,16,2) for
16x2 LCD.

//Variable setup

unsigned long prevTime = 0;

unsigned long newTime = 0;

unsigned long runningTime =0;

float RPM = 0;

int interval = 1000;

int count = 0;

int delayTime = 1;

float timeElapsed =0;

// the setup routine runs once when you press reset:

void setup() {
```

```

// initialize serial communication at 9600 bits per second:

Serial.begin(9600);

pinMode(ledPin, OUTPUT);

//<===== Initiate the LCD =====>

lcd.init();

lcd.backlight();

}

// the loop routine runs over and over again forever:

void loop(){

  // read the input on analog pin 0:

  int sensorValue = analogRead(A0);

  newTime = millis();

  runningTime = ((newTime))/(1000*60);

  if (sensorValue > 500){

    digitalWrite(ledPin,HIGH);

    count = count +1;

  }else{

    digitalWrite(ledPin,LOW);

  }
}

```

```
if (newTime - prevTime >= interval ){  
  
    timeElapsed = newTime - prevTime;  
  
    RPM = -(count*1000*60)/timeElapsed;  
  
    prevTime = newTime;  
  
    count=0;  
  
}
```

```
// Serial monitor display
```

```
Serial.print("RPM = ");
```

```
Serial.println(RPM);
```

```
Serial.print("Count = ");
```

```
Serial.println(count);
```

```
Serial.print("Time Elapsed = ");
```

```
Serial.println(timeElapsed);
```

```
Serial.print("Running Time = ");
```

```
Serial.println(newTime);
```

```
Serial.println(" minutes");
```

```
//LCD display code
```

```
lcd.setCursor(0, 0);
```

```
lcd.print("...OUTPUT...");
```

```
lcd.setCursor(0, 1);
```

```
lcd.print("RPM = ");  
  
lcd.setCursor(8, 1);  
  
lcd.print(RPM);  
  
lcd.setCursor(0, 2);  
  
lcd.print("Time = ");  
  
lcd.setCursor(8, 2);  
  
lcd.print(newTime);  
  
delay(delayTime);  
  
}
```