REGENERATIVE BRAKING: DELIVERABLE 2

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Executive Summary

The Regenerative Braking System Model's comprehensive design and implementation strategy, created as part of the ECTE250 project, are presented in this study. Through the conversion of kinetic energy lost during braking into electrical energy, the system seeks to improve sustainability and reduce energy waste. This project's integration of embedded systems, hardware design, and IoT is in line with the course objectives.

Given that it improves mileage, decreases the need for frequent recharging, and lowers long-term operating expenses, the suggested regenerative braking system is especially advantageous for electric and hybrid vehicles. Furthermore, the technology has wider uses outside of the automobile industry, such as energy recovery in smart buildings, industrial machines, and elevators.

An Arduino microcontroller, a DC motor with a generator function, an H-Bridge circuit, energy-storing capacitors, voltmeter and an Ethernet shield for Internet of Things integration constitute crucial parts. The system's online dashboard and LCD display are intended to allow real-time tracking of carbon offset and recovered energy.

The report includes a comprehensive discussion on design implementation, testing strategies, alignment with project requirements, and a structured project plan. A detailed budget analysis and marketing strategy for the Innovation Fair are also provided. The findings of this report reinforce the environmental and economic benefits of regenerative braking technology, contributing to a more sustainable future.

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1. Introduction

1.1. Overview

In the modern day of infrastructure and transportation, the shift to energy-efficient solutions is essential. By recovering and reusing energy that would otherwise be lost as heat, regenerative braking is a cutting-edge technique that improves energy conservation. In order to increase efficiency, lessen dependency on external power sources, and promote environmental sustainability, this technology is frequently used in electric and hybrid vehicles [1].

In order to show how kinetic energy can be effectively transformed into electrical energy and then reused, this project focuses on creating a model of a regenerative braking system. A motor-driven flywheel, braking system, energy recovery circuit, and an Internet of Things-based monitoring interface make up the system. For remote tracking, the real-time data gathered by voltage and current sensors is sent via an Ethernet shield and shown on an LCD.

1.2. The Physics Behind Regenerative Braking

Regenerative braking is based on several fundamental physics principles, including Newton's Laws of Motion, the Law of Conservation of Energy, and Faraday's Law of Electromagnetic Induction. These ideas clarify how the system effectively absorbs, transforms, and uses energy.

The Laws of Motion by Newton

A vehicle in motion has kinetic energy proportionate to its mass and velocity, according to the First Law of Inertia. Without external force, it continues moving. This kinetic energy is wasted in conventional braking because frictional force turns it into heat. This kinetic energy is diverted and stored during regenerative braking.

The wheels experience a force when braking is applied, according to the second law (Force = Mass × Acceleration). Regenerative braking transforms force into electrical energy rather than releasing it as heat.

The Law of Conservation of Energy

According to this fundamental principle, energy can only be transformed from one form to another; it cannot be created or destroyed. Regenerative braking transforms the moving vehicle's kinetic energy into electrical energy instead of wasting it as heat. Battery recharge or vehicle component powering are two uses for this recovered energy.

The Law of Electromagnetic Induction by Faraday

According to this equation, an electromotive force (EMF) is induced when the magnetic flux through a conductor changes. When the car slows down while using regenerative braking, the motor goes into generator mode. The motor's coils generate an electric current in response to the wheels' rotation, which transforms mechanical energy into electrical energy.

1.3. Uses Beyond Automobiles

Despite being primarily linked to automotive applications, the concepts of regenerative braking can be used in a variety of industries:

1. Elevators and escalators: Other building systems can be powered by energy recovered during downward motion [2].

2. Industrial Machinery: To maximize energy efficiency, factories might install regenerative braking in cranes and conveyor systems [3].

3. Public Transit Systems: Regenerative braking is a technique used by electric trains and trams to return power to the grid, lowering the total amount of energy required [4].

4. Smart Buildings: Energy-efficient infrastructure and HVAC systems with integrated regenerative braking can help reduce energy costs and promote sustainable operation [5].

1.4. Competitive Edge and Impact

The creation of this regenerative braking model offers a benefit by showcasing an energy recovery system that is both affordable and expandable. This technology reduces operating costs and encourages environmental responsibility by converting kinetic energy into reusable electrical power, in contrast to conventional braking systems that produce excessive heat and waste energy [6]. Incorporating IoT-based monitoring also enables predictive maintenance, data-driven analysis, and energy efficiency.

2. Alignment of Regenerative Braking

2.1. Environmental Alignment

By drastically lowering carbon emissions, regenerative braking promotes environmental sustainability. It reduces fuel usage in hybrid and electric cars (EVs), which in turn reduces greenhouse gas emissions, by recovering energy that would otherwise be lost as heat. Additionally, it encourages energy efficiency since, in contrast to conventional braking systems that release kinetic energy as heat, it transforms it back into useful electricity. Furthermore, regenerative braking improves sustainability by lowering reliance on fossil fuels when combined with renewable energy sources for recharge [7].

2.2. Economic Alignment

Regenerative braking has significant financial advantages. Because it uses less fuel and energy, clients save money this way. Lower maintenance and replacement costs result from the mechanical brake components experiencing less wear and tear. Furthermore, governments all around the world provide incentives for electric and hybrid cars, which subtly encourage the use of regenerative braking technology. Additionally, because of their improved efficiency and lower maintenance costs, cars using this system frequently have higher resale values. Lastly, the development of regenerative braking technology promotes research into energy-efficient car parts and investments in renewable energy sources [8] [9].

2.3. Technological Alignment

Modern electric and hybrid cars must have regenerative braking in order to improve energy management overall. The technology complements intelligent mobility solutions and smart grid systems, and it is in line with developments in smart transportation. It also encourages the creation of energy storage devices that improve efficiency and energy retention, like supercapacitors and advanced battery technology. Regenerative braking adds to the larger technological developments in the energy and automotive industries by combining with these technologies [9] [10].

2.4. Policy and Regulatory Alignment

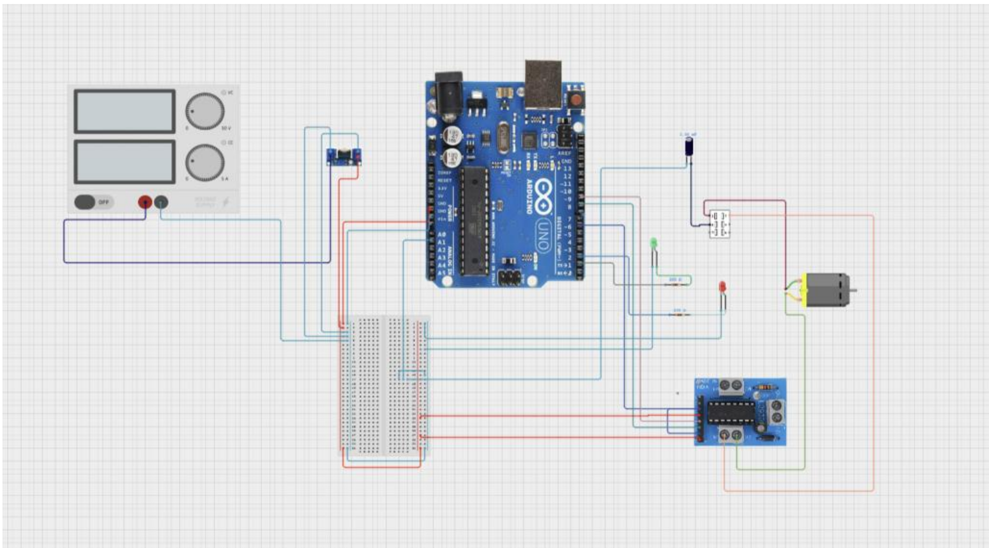
Manufacturers of automobiles use regenerative braking to help them fulfill the strict emission regulations set by environmental authorities. As part of their objectives for sustainable mobility, several governments and places around the world support electrified transportation. Regenerative braking contributes to the sustainability of urban transit and complies with international environmental initiatives that aim to reduce pollution and energy waste by conforming to these policies [11].

2.5. Cost Considerations

Regenerative braking can save money in the long run, but because it involves advanced technologies and battery systems, it costs more to adopt initially. However, because EVs and hybrids require less maintenance, are more efficient, and have longer component lifespans, the long-term advantages offset these upfront expenditures. Broad use of regenerative braking can also lessen reliance on imported fossil fuels, which will increase energy cost stability. Because they use less energy and wear down brake systems less frequently, cars with regenerative braking systems typically fetch higher resale values. Increased investment in research and development is also a result of the continuous improvements in regenerative braking technology, which promotes innovation in green technologies and energy-efficient car parts [8] [10] [11].

3. Design

3.1. Circuit Diagram



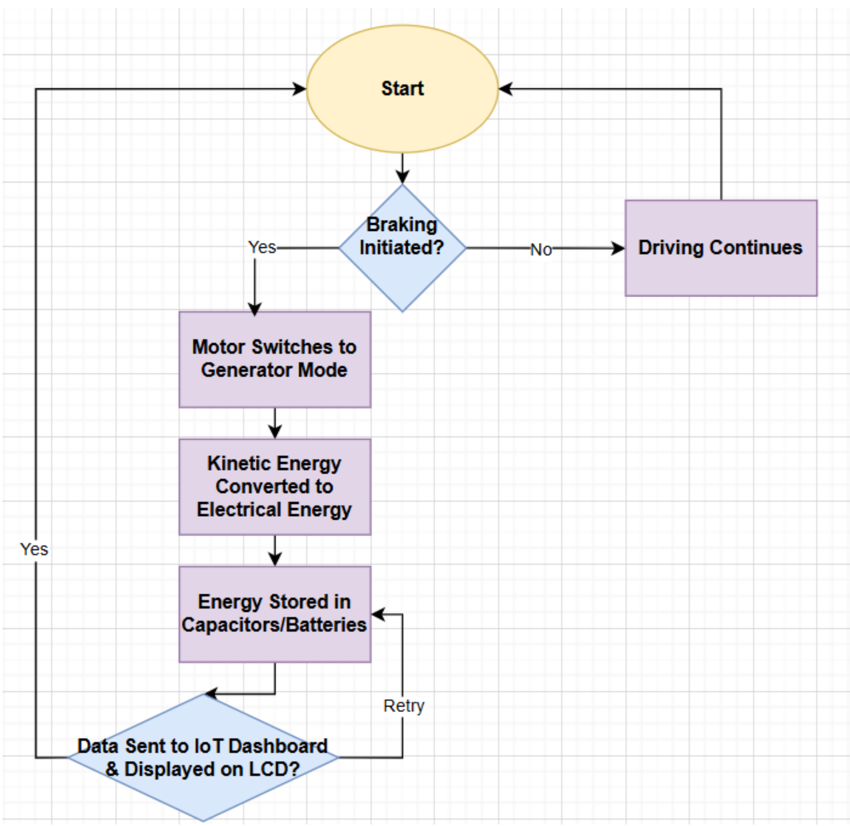
This is the model circuit diagram. The DC motor can work either as the motor or as a generator depending on the circumstances. When driving, the motor works normally by converting electrical energy to mechanical energy but when braking, the motor acts as a generator and produces current which is stored in the 1 mF capacitor.

The L298D works as the motor driver where the D9 pin acts as the PWM signal for the enable. The D12 pin controls one terminal of the motor and is connected to input 1 of the L298D while the D13 pin controls the other terminal and is connected to input 2 of the L298D. The output 1 is connected to pin 2 of the DPDT switch which is connected to one of the motor terminals while the output 2 of the l298d is connected to the other motor terminal. (The L298D will be replaced by L298N as it is a better alternative as it has a heatsink, the DPDT will be replaced by SPDT and only 1 switch connected to outputs is needed)

The LED connected to the D5 pin lights up when the system is in drive and the D4 pin lights up when system is braking. The A0 pin is used to measure the instantaneous voltage across the capacitor and display it on the LCD (not in diagram as connections become unclear).

A voltage regulator is used to make sure that no matter what voltage is used the Arduino and other components receive only 5V another voltage regulator can be used to make sure that the voltage generated does not surpass 5V. A separate connection can be made to the motor using a 2nd channel of the power supply to make it rotate faster.

3.2. Flowchart



Braking Initiated

- The system determines if the brakes are applied.
- If No, vehicles continues driving and the regenerative braking system is not implemented
- If Yes, The motor switches to the generator mode.

Motor Switches to Generator Mode

- When braking is detected, the motor shifts from acting as a drive motor to functioning as a generator.
- This means that instead of consuming electrical energy, the motor starts producing electricity.

Kinetic Energy Converted to Electrical Energy

- As the motor functions as a generator, it converts the kinetic energy into electrical energy.

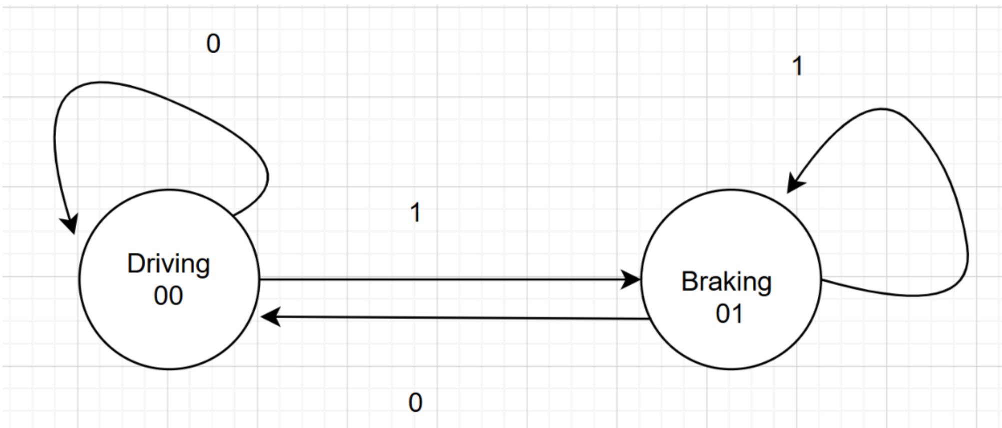
Energy Stored in Capacitors/Batteries

- The generated electrical energy for later use.
- The stored energy can later be reused for acceleration or other electrical functions in the vehicle.

Data Sent to IoT Dashboard & Displayed on LCD?

- The system attempts to transmit data about energy recovery to an IoT-based monitoring system and display it on an LCD.
- If successful, the process is completed, and the system returns to the driving state.
- If the data transmission fails, the system retries sending the information.

3.3. State Diagram



Components:

- **Input:** A button (SPDT).
- **Output:** A DC motor (its state changes based on the button press).

State Descriptions:

1. Driving State (00)

- The motor is active and spinning.
- If the button is not pressed **(Input = 0),** the system stays in this state.
- If the button is pressed **(Input = 1),** the system transitions to the Braking state.

2. Braking State (01)

- The motor is stopped or in a braking mode.
- If the button is not pressed **(Input = 1),** the system stays in this state.
- If the button is pressed **(Input = 0),** the system returns to the Driving state.

Transitions:

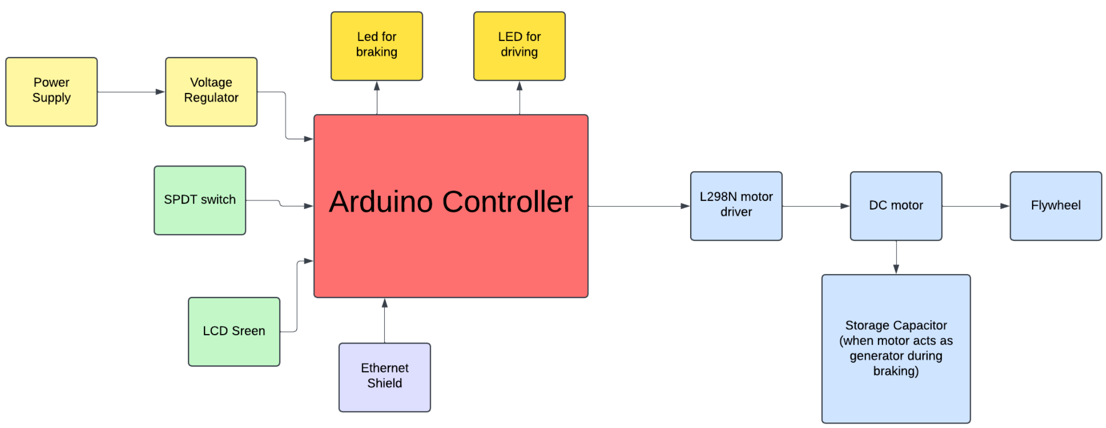
- **From Driving (00) to Braking (01) on Input = 1**

    - When the button is pressed (input = 1), the Finite State Machine Transitions to the braking state.

- **From Braking (01) to Driving (00) on Input = 0**
    - When the button is pressed (input = 0), the Finite State Machine transitions back to the driving state.

The Arduino controller will automatically manage the state transitions once this logic has been written. Design and planning can benefit from the FSM, but once the logic is programmed into the Arduino, we won't need to consult the state diagram any more.

3.4. Block Diagram



This diagram shows how the connections are made. The power supply is connected to the voltage regulator to make sure voltage does not exceed 5V. The SPDT switch is used to switch between braking and driving, when the button is pressed the system starts braking and the motor acts as a generator and stores electrical energy in the capacitor. The flywheel is used to store kinetic energy and when the system is in braking phase the kinetic energy is converted to electrical energy. There are 2 LED’s that show the current state of the system and an LCD that shows the voltage across the storage capacitor.

4. Testing

Testing is the process of analyzing the system to detect the differences between the existing and required conditions. Without testing the system may not perform as required, therefore multiple tests and multiple testing rounds will be conducted to make sure that the system functions perfectly.

4.1. LCD Test

A LCD will be used to display the voltage across the capacitor. The LCD will be tested to make sure it can accurately display the voltage by comparing it with the voltage measured by the multimeter.

4.2. LED Test

LED's will be used to show that energy is being stored in the capacitor. LED's must be tested to make sure that they do not break down easily and can work in long term.

4.3. Motor Test

Motors will be tested to make sure they can handle the flywheel and produce good results. Comparisons between permanent magnet brushed motor and a brushed DC motor will be made by checking its compatibility with the L298N driver along with the emf produced when it works as a generator.

4.4. Simulation Test

A simulation test will occur to make sure that the simulation runs smoothly and that everything works well. The TinkerCAD simulation will not be very accurate as a flywheel cannot be used and therefore the motor cannot function as a generator, but it will help us confirm if the motor starts and stops properly when the simulation runs. In Multisim we check show the motor running and coming to a stop when a switch is flipped.

4.5. Flywheel Test

A test will be run to check how the flywheel will run and if there are any problems during acceleration and deceleration. To do this the flywheel will be rotating at maximum speed for a certain duration to make sure there are no problems with the rotation. Multiple rounds of testing will take place to ensure that the flywheel is durable.

4.6. Prototype Testing

The prototype may not function as well as the simulation shows. To make sure the prototype performs efficiently, multiple testing rounds will take place to make sure that the system works perfectly, and the amount of energy saved meets the criteria.

5. Planning

The project consists of 8 deliverables in total and we are provided 22 weeks/5 months to show our work. The work starts in mid-January and ends in June. This section shows how the work is divided along with the timeline of the work. It also includes precautions for certain risks.

5.1. Division of Work and Timeline

The objective of deliverable 1 was to present the ideas of the group to the judges and obtain feedback to choose one of the projects and improve upon the idea. It took around 2 weeks to come up with ideas, research on the idea, check the feasibility of the ideas based on the budget provided and impact of the creation in different industries and society. The presentation took place 4 weeks after the start of the course.

The objective of deliverable 2 is to create a detailed report explaining the idea selected, how the budget is divided, the materials required, the timeline of the project, the testing protocol and design of the machine. It took 2 weeks to research and complete the report.

The objective of deliverable 3 is to make a simulation of the design and show how it works. A report which contains the results of the simulation along with some comparisons will also be submitted. This will take around 2 weeks to complete for the simulation and report all together.

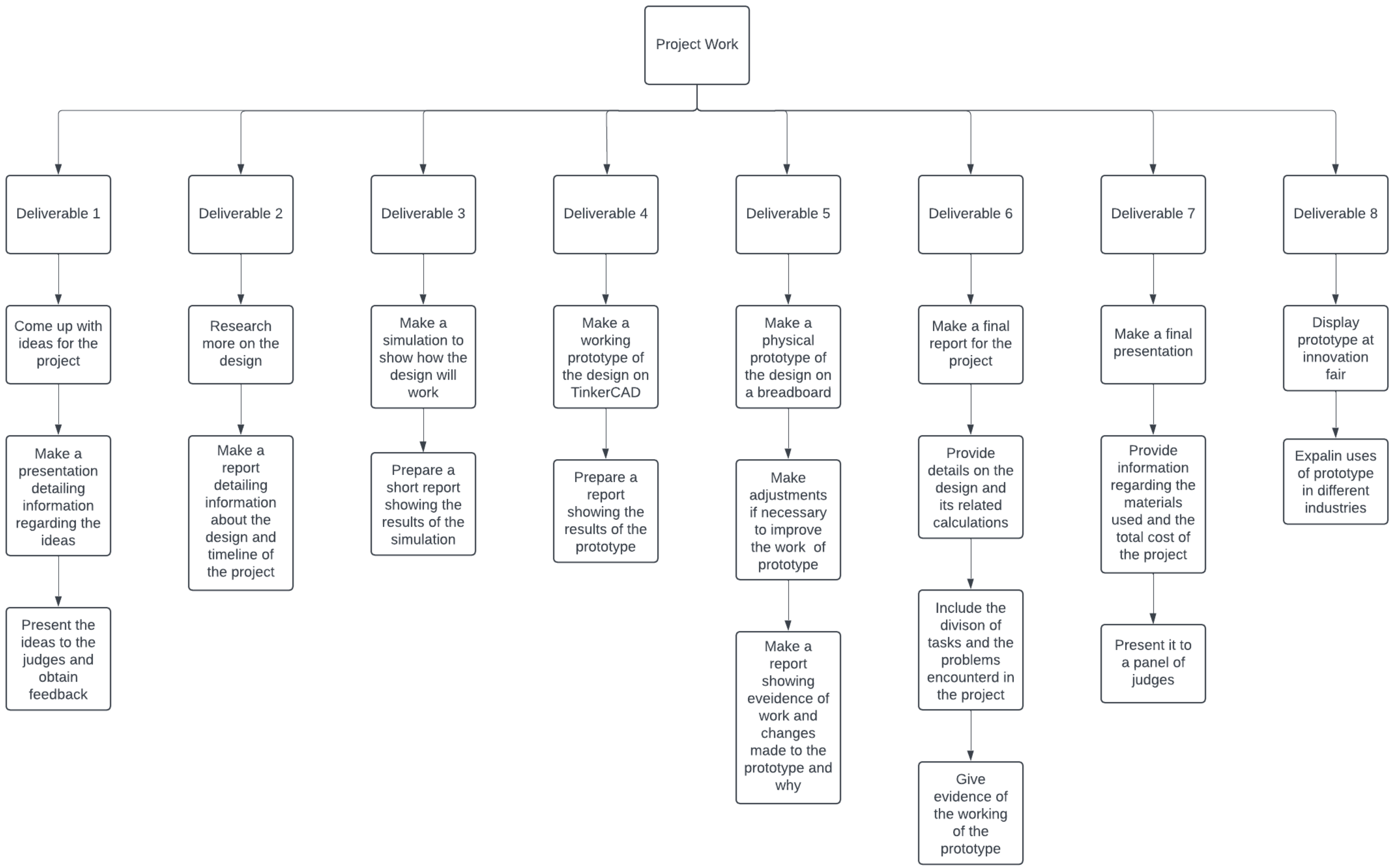
The objective of deliverable 4 is to show the working of the design on TinkerCAD and submit a report detailing the working of the design prototype. This may take around 2 to 3 weeks to complete.

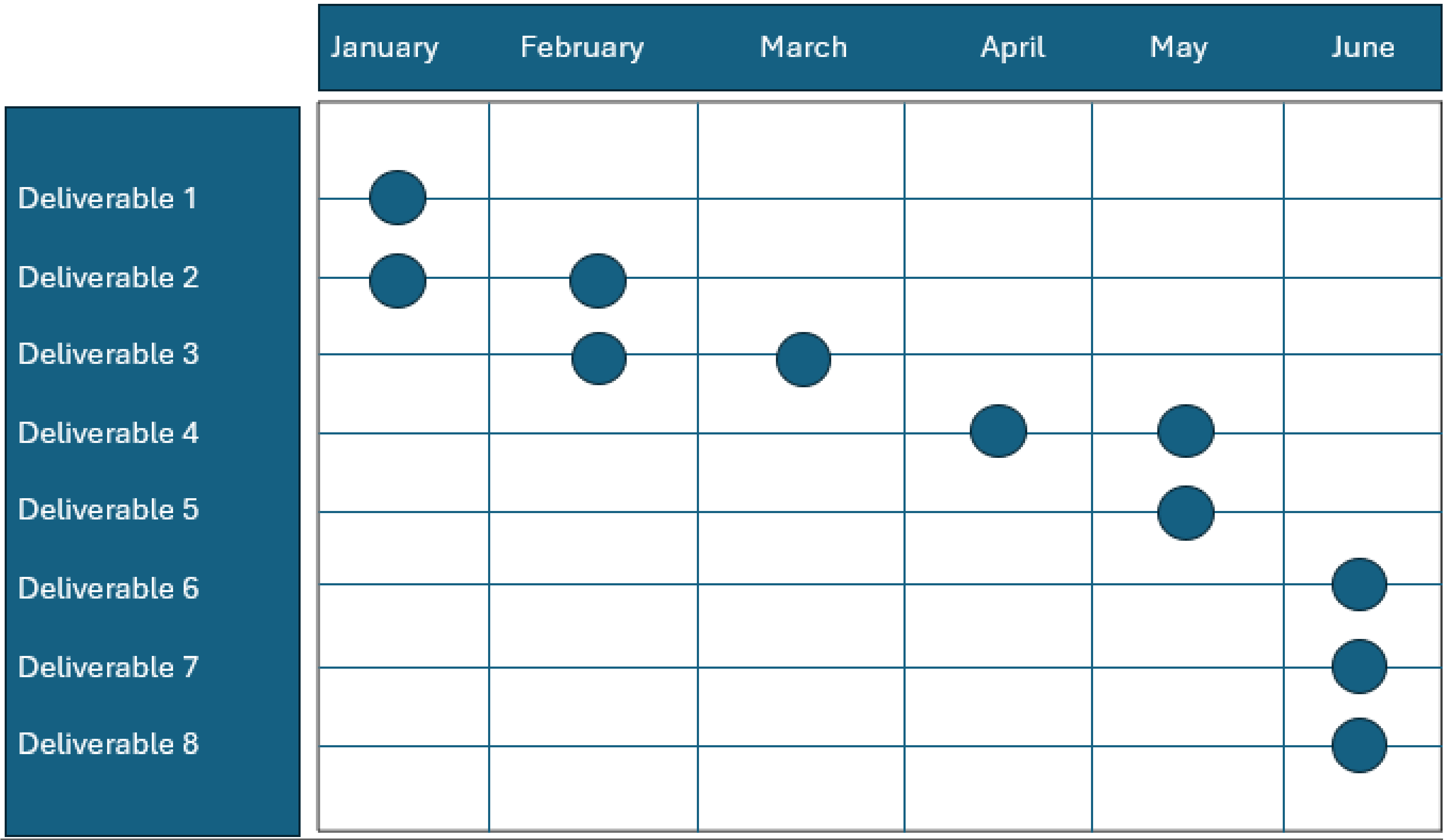
The objective of deliverable 5 is to make a physical prototype of the design on a breadboard to check the effectiveness of the design and see if any improvements can be made. A report will also be submitted detailing the results of the prototype and if any changes are made. This will take around 3 weeks to complete.

The objective of deliverable 6 is to make a report detailing the work done for the project such as the design, the related calculations, the testing procedures, changes made to the design, problems encountered during the project and the work done to fix the problem, the contributions of the members during the project and the final perfoboard working prototype. This will take around 2 weeks to complete.

The objective of deliverable 7 is to make a presentation detailing the design activity, the plan followed by the group, the materials used for the design and budget used to make the design. It will also contain evidence of the working of the perfoboard working prototype. This will take 2 weeks to complete.

The objective of deliverable 8 is to display the prototype at the innovation fair to show how the prototype works and its uses in specific industries. This will take a week to prepare and will be presented towards the end of June.


Project Work
Deliverable 1
Come up with ideas for the project
Make a presentation detailing information regarding the ideas
Present the ideas to the judges and obtain feedback
Deliverable 2
Research more on the design
Make a report detailing information about the design and timeline of the project
Deliverable 3
Make a simulation to show how the design will work
Prepare a short report showing the results of the simulation
Deliverable 4
Make a working prototype of the design on TinkerCAD
Prepare a report showing the results of the prototype
Deliverable 5
Make a physical prototype of the design on a breadboard
Make adjustments if necessary to improve the work of prototype
Make a report showing eveidence of work and changes made to the prototype and why
Deliverable 6
Make a final report for the project
Provide details on the design and its related calculations
Include the divison of tasks and the problems encounterd in the project
Give evidence of the working of the prototype
Deliverable 7
Make a final presentation
Provide information regarding the materials used and the total cost of the project
Present it to a panel of judges
Deliverable 8
Display prototype at innovation fair
Expalin uses of prototype in different industries


January
February
March
April
May
June
Deliverable 1
Deliverable 2
Deliverable 3
Deliverable 4
Deliverable 5
Deliverable 6
Deliverable 7
Deliverable 8

Deliverable No.	Start Date	End Date	Duration (in Days)
Deliverable 1	6th Jan	27th Jan	22
Deliverable 2	28th Jan	25th Feb	29
Deliverable 3	25th Feb	20th Mar	25
Deliverable 4	14th Apr	5th May	22
Deliverable 5	6th May	30th May	25
Deliverable 6	1st June	24th June	24
Deliverable 7	8th June	22nd June	15
Deliverable	22nd June	29th June	8

The image shows for which months the team is working on which deliverable and the table gives more explanation regarding the start of the task and its end along with its duration.

5.2. Risks

This project requires an enormous amount of electrical work, which has the highest risk of causing hazards. Mishandling electrical components can result in injuries such as electrical shocks or burns. To prevent such accidents from happening safety equipment will be worn at all times and proper methods will be followed when using electrical equipment. The voltage regulator can get too heated and can get damaged, to prevent this a voltage regulator with heat sink will be used as the heat sink regulates the temperature of the device.

6. Finance

6.1. Materials Budget

For this project the budget for parts was set to AED 900. The most expensive part of this budget is taken up by the Arduino Starter Kit costing AED 250.This gives an additional AED 650 that is available to be spent for the development if this project.

The kit comes with the Arduino board and many other basic parts required .

Apart from this a few other parts as seen below is required.

Items	Estimated quantity	Cost(AED)	Source
lm317 dc-dc buck module with heatsink (voltage regulator)	3	26.79	Amazon
l298N motor driver with heatsink	3	28	Amazon
1D20 SPDT Slide Switch 5MM	3	3	PCB Blue
1D15 130 Micro DC Motor	3	30	PCB Blue
Eujgoov 31ZY Permanent Magnet Motor	3	122.43	Amazon

The total adds up to AED 460.22 with the components and the Arduino starter kit. The selected parts are based on the team's current understanding of the requirements for building the prototype, but some components may be added or removed as needed. From this it is evident that the total cost to build the prototype is completely within the given budget (for parts). Other equipments are required for the project but is provided by the university and therefore doesn’t add up to our budget.

6.2. Labour and Consultation Cost

Task	Time of labor	Cost (AED)
Deliverable 1(project proposal)	4 hours	1200
Deliverable 2(detailed design)	12 hours	3600
Deliverable 3(design stimulation)	5 hours	1500
Deliverable 4(Tinkercad prototype)	9 hours	2700
Deliverable 5(Breadboard prototype)	16 hours	4800
Deliverable 6(Final design report)	30 hours	9000
Deliverable 7(Final design presentation)	5 hours	1500
Deliverable 8(innovation fair)	3 hours	900
Total	**Total hours = 84 hours**	**Total cost = 25200 Dhs**

Consultation With	Estimated time required	Costs (AED)
Academic Staff	3 hours	1500
Tutor/lab engineer	5 hours	2000
Total	**8 hours**	**3500**

The team has estimated the time required for each deliverable based on the hours we used so far and expecting to use in the future. This has resulted in a projected cost of AED 25,200 for a total of 82 hours over 8 deliverables. Additionally, consultation fees of AED 3,500 bring the total estimate to AED 28700.

Even though there is no strict budget limit has been set for this project, the team wants to reduce the cost as much as possible as the team is committed to maximizing efficiency. The labor wages also could be varied as this is just an estimate and the time spent per deliverable is subjected to change.

7. Marketing

The team has moved forward with a project based on charging of batteries in car and therefore the main industry aimed is the automotive industry. The main aim is to spread the device more into the industry. It is already observed in many EV's and in hybrid cars. In UAE, we can now see a drastic shift from the people from traditional petrol cars to hybrids and EV's. This helps in increase of such a product in the industry and increases its demand due to how useful it is.

The goal is to make such a device widespread not only in UAE. The automotive regenerative braking system market in Middle East & Africa is expected to reach a projected revenue of US$ 455.9 million by 2030. A compound annual growth rate of 12.4% is expected of Middle East & Africa automotive regenerative braking system market from 2025 to 2030. This statistic shows the scope of the system.

To achieve our goal the team is planning on partnering up with already established companies to promote our product. doing so can help us scale faster by leveraging their resources, credibility, and market reach. We expect to gain more popularity and exposure to the people. Target Industries for Partnerships can be automotive companies such as Al Futtaim automotives, EV companies such as Masdar, Tesla etc.

Another approach planned is to advertise and market our product in summits and exhibitions. The UAE is a stage for multiple of such events such as EVIS (Electric Vehicle Innovation Summit) ,World Future Energy Summit (WFES), GITEX Technology Week etc. Marketing here increase the exposure of the product highly.

The group feels that the scope of regenerative braking doesn't stay just in the automotive industry but also in places where much mechanical force as applied with possibilities of converting energy.

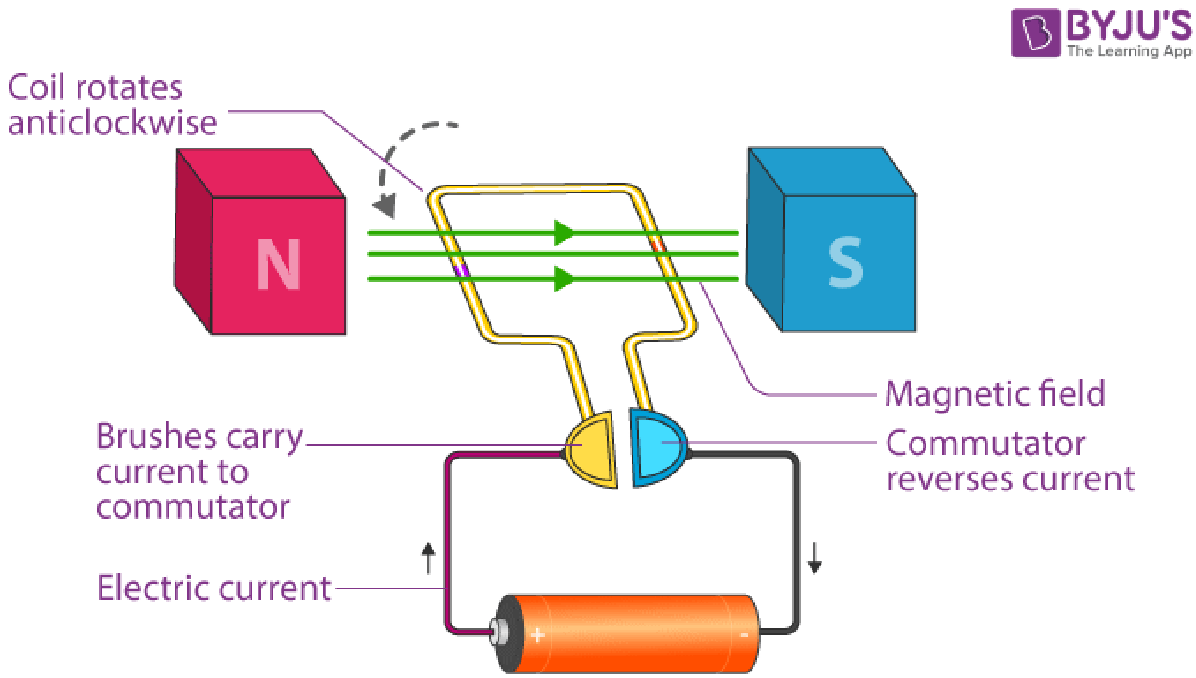
One of such possibilities is In the field of Industrial Machinery & Manufacturing. Cranes and lifting equipment, such as those used in ports, warehouses, construction sites, etc, require frequent braking while handling heavy loads. Regenerative braking can significantly improve energy efficiency and enhance sustainability. This is already seen in some companies abroad. This shows the increase in scope and range in industries where our product would be applicable.

Marketing for this can also be approached with partnerships and exhibitions at similar events.

Although we haven't gone much deep into it, we have kept digital marketing as a method to showcase our product given the effect of internet and its impact on this generation. The team has discussed the pros such as wide reach, cost effectiveness etc., and therefore kept this as a valid option.

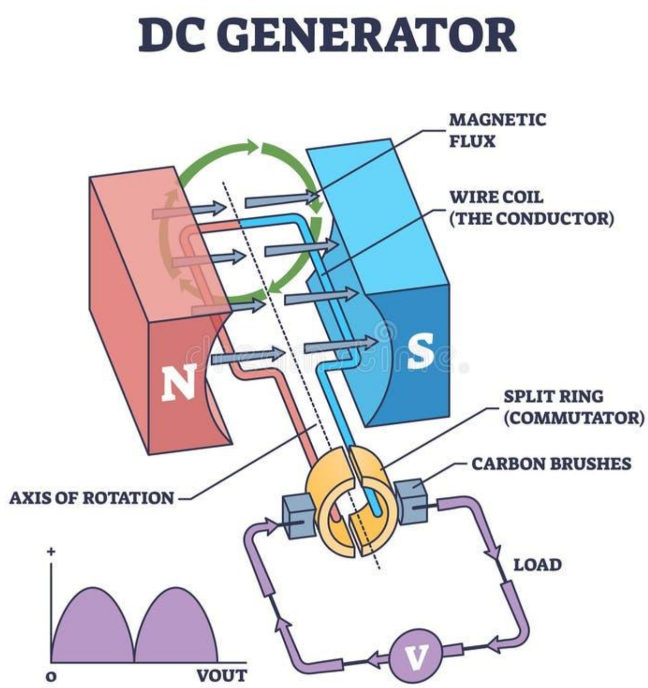
Appendix

Working of Motor



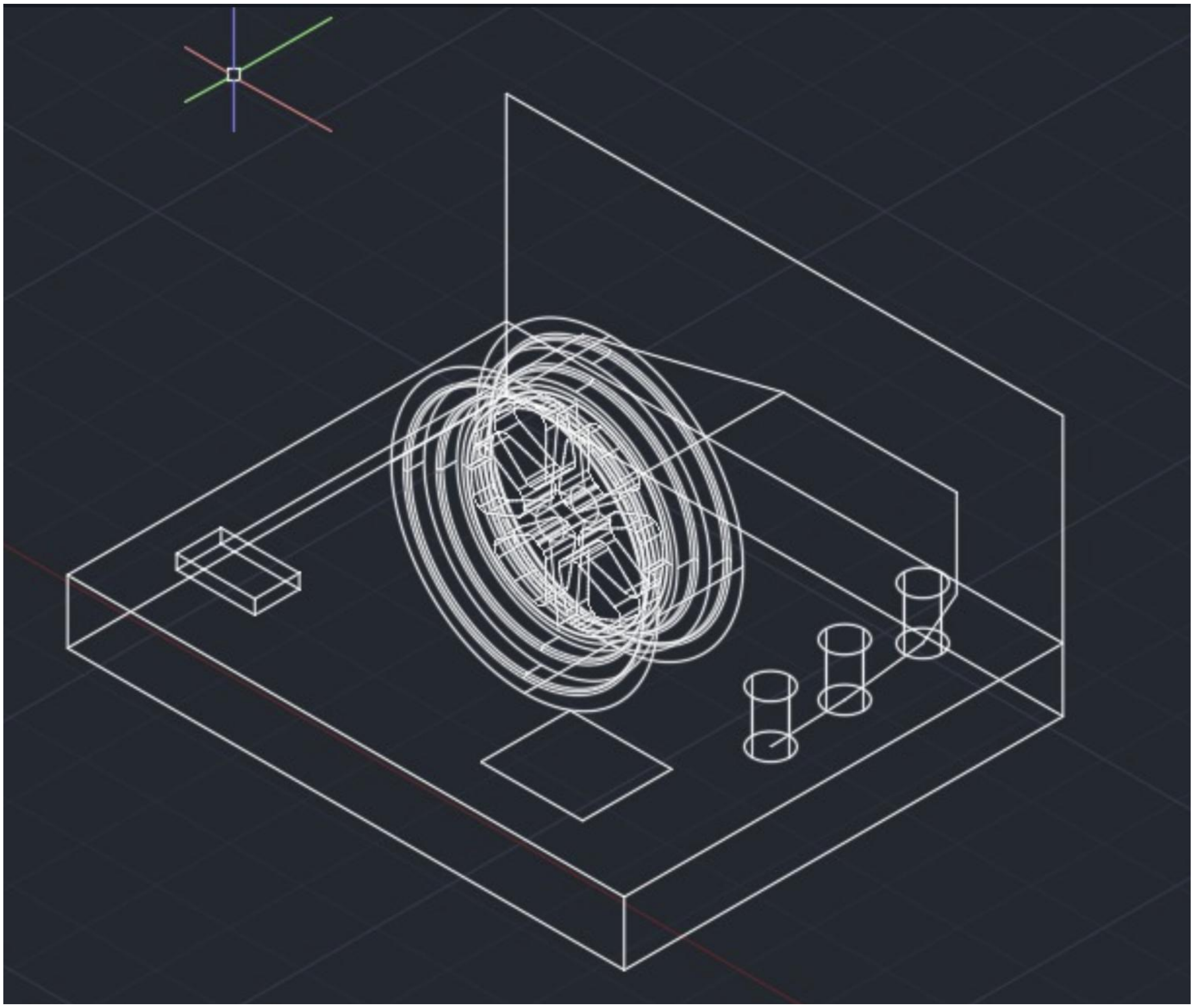
A motor is a device that converts electrical energy to mechanical energy. The principle behind electric generator is the that when current is passed through the coil, a magnetic field is produced but due to the presence of the external magnetic field it experiences a force that makes it rotate. The direction of rotation can be determined using Flemming's Left Hand Rule which states that when you stretch the thumb, forefinger, middle finger of your left hand such that all three are mutually perpendicular to each other such that the forefinger points in the direction of magnetic field and middle finger points in the direction of current, then the thumb points in the direction of force. A split ring is used as a commutator that reverses the direction of current when the coil rotates to its maximum height so that the coil experiences in force in the same direction to complete its rotation.

Working of Generator



A generator is a device that converts mechanical energy to electrical energy. The principle behind electric generator is Electromagnetic Induction which states that when the magnetic field passing through the coil varies a current is induced which opposes the change in magnetic field. The direction of rotation can be determined using Flemming's Right Hand Rule which states that when you stretch the thumb, forefinger, middle finger of your left hand such that all three are mutually perpendicular to each other such that the forefinger points in the direction of magnetic field and thumb points in the direction of force, then the middle finger points in the direction of induced current. A split ring is used as a commutator that reverses the connection of the coil to the brushes in order to ensure that current flows in one direction only.

3D Model



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