Design And Fabrication of Regenerative Braking System

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Under the supervision of

Nuruzzaman Rakib

Lecturer

Department of Mechanical Engineering

SUBMITTED BY

1.Md Ariful Islam	[BME1703013382]
2.Md Jashim Uddin	[BME1803016238]
3.Rayhanul Islam	[BME1803016269]
4.Md Mostafijur Rahaman	[BME1803016270]

Submitted to the Department of Mechanical Engineering
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of
Bachelor of Science in Mechanical Engineering

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DECLARATION

Design And Fabrication of Regenerative Braking System

Submitted to the Sonargaon University, recorded of an Original Work Done by us. Under the Guidance of Nuruzzaman Rakib, Lecturer of Sonargaon University.

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1.Md Ariful Islam	[BME1703013382]
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Supervisor

Nuruzzaman Rakib

Lecturer of Mechanical Engineering

Sonargaon University (SU)

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At first, we are grateful to the Allah subhanahu wa ta'ala. Without the blessing of the Allah subhanahu wa ta'ala, we couldn't reach this far. Allah subhanahu wa ta'ala is the Greatest Planner.

We would like to thank Nuruzzaman Rakib, Lecturer of the Department of Mechanical Engineering. We are blessed to get an opportunity to work with him. Throughout the thesis, he was very helpful, dedicated and loyal with us. He was strict, ambitious and always encouraged us to work harder. With his proper guidance and valuable time, this thesis was possible to complete in time.

ABSTRACT

In this thesis, series-parallel hybrid electric vehicle (Toyota, Prius THS II) is studied. The energy storage system of this vehicle is batteries. It is not good to use batteries or ultra-capacitor alone. In this thesis, two energy storage devices are used together to form the hybrid energy storage system. The advantages of this hybrid energy storage system are the combined advantages of the two energy storage devices. The two devices compensate the drawbacks of each device. A performance of series-parallel hybrid electric vehicles (Toyota, Prius ths II) using hybrid energy storage system are presented. The hybrid energy storage system consists of nickel-metal hydride batteries and ultra-capacitors. The hybrid storage system is designed to reduce the total weight of the energy storage system and in turn increase the overall efficiency. The ultra-capacitor contributes to the rapid energy recovery associated with regenerative braking and to the rapid energy consumption associated with acceleration in electric vehicles. This Ultracapacitor allows acceleration and deceleration of the vehicle with minimal loss of energy and minimizes the stress of the main batteries by reducing high power demands away from it. It also leads to longer battery life by extracting energy at a slower average rate. This paper analyzes and compares between the performances of the series-parallel hybrid electric vehicles with the proposed hybrid storage system (batteries/ultra-capacitors) and with the conventional storage system (batteries only). Simulation works are carried out to evaluate the performance of the two storage systems under different operating conditions such as acceleration, constant speed and deceleration.

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LIST OF ABBREVIATIONS

Bhp	Brake horse power
Cm	Centimeter
EMBS	Electromagnetic Braking System
Mph	Miles per hour
RPM	Revolution per minute

NOMENCLATURE		DIMENSION
A	Ampere	[A]
R	Radius	[L]
V	Voltage	$[ML^2T^{-3}A^{-1}]$

CHAPTER 1

INTRODUCTION

1.1 Background and Rational

Regenerative braking is a method of recovering energy lost during braking and storing it as electrical energy in the battery.

As you press the car's brakes, kinetic energy generates, which uses to move the car forward. It normally generates heat by the brake pads. However, hybrid vehicles' regenerative braking technology can convert this dissipated heat into electricity.

When you squeeze the accelerator, the battery delivers power to drive the motor. As the motor receives power, it moves the wheels.

It reverses the process as you remove your foot off the accelerator or apply the brake. Power to the electric motor is cut, and the wheels transfer kinetic energy to the electric motor, essentially turning it into a generator and feeding power back into the battery.

All hybrids are also fitted with standard friction brake discs for sudden stops, as regenerative braking is not suitable for sudden stops.

1.2 Motivation

An electric vehicle provides a clear alternative to the internal combustion engine vehicles which run on fossil fuels like petrol and diesel. The fuels are depleting fast and alternative energy resources must be used as the consumption of fossil fuels goes on increasing every year due to usage of more vehicle but the production of these fuels is not keeping pace with the increasing demand. An electric vehicle provides many benefits as mentioned above and is environmentally friendly. Because of such benefits of electric vehicles, it is important that an electric vehicle be given the latest systems in braking, as it is an important part in the use of any vehicle. Braking systems like ABS and regenerative braking which will make the electric vehicle safer and easier to use as well as make it energy efficient should be implemented in the vehicles. If such systems are incorporated in electric vehicles and their advantages are seen by all, then the use and sale of electric vehicles all over the world will increase, especially in India which has a huge market for vehicles and is suffering from the ill effects of pollution due to vehicles in major cities. Increase in the number of electric vehicles will be beneficial to the society and to the environment. Also, wide use of Anti-lock Braking System will lead to fewer accidents on the streets and will save many lives by preventing many accidents.

1.3 Objectives

Objective

As the basic law of Physics says, "Energy can neither be created nor be destroyed it can only be converted from one from to another."

According to the law of Physics, the automobile wasted energy we will reuse or reserve.

1. To build a circuit for Anti-Lock Braking System which will prevent the skidding of wheels during hard braking and keep the control of the vehicle at all times with the driver in Electric Vehicles by keeping the slip ratio in the control region.

2. To include a Regenerative Braking sub-system which will recover lost energy in the circuit and give it back to the battery.

1.4 Advantages

The advantages of Regenerative Braking are-

i. Energy which is wasted in frictional braking is recovered here.

ii. As load on frictional braking reduces, brake pads last longer.

iii. Energy is given back to battery which increases battery life and vehicle mileage.

1.5 Disadvantages:

The disadvantages of Regenerative Braking are-

i. It cannot be used a standalone braking system and friction brakes too are required.

ii. Regenerative brakes are not that effective at lower speeds

iii. Regenerative braking can be used only on wheels which are driven by motor i.e., only the front axle or the rear axle.

CHAPTER 2

HYBRID ELECTRIC VEHICLES

LITERATURE REVIEW

2.1 HYBRID VEHICLES

The combination of two or more power sources is known as a hybrid. The vehicle designed on hybrid technology is known as a hybrid vehicle. Hybrid electric vehicle (HEV) includes in the world's most famous vehicles. A hybrid electrical car has two power sources: an I.C. engine and the other is an electric motor. The I.C. engine and electric motor are used in the hybrid car to increase the vehicle power and reduce the emission rate. The engine is known as the heart of the vehicle. This is the engine that converts the power of the fuel into the motion of the car.

Any vehicle which can be powered by two or more power sources is called a Hybrid vehicle. A hybrid car is a type of vehicle which uses both the electric motor and I.C. engine as a power source is not possible to connect a hybrid electric vehicle to charge the battery. Instead, the battery is charged by regenerative braking and an I.C. engine. The extra power provided by the electric motor can potentially allow for smaller engines.

The battery also powers the auxiliary load and reduces engine idling when stopped. These two power sources (electric motor and I.C. engine) improve fuel economy without sacrificing performance.

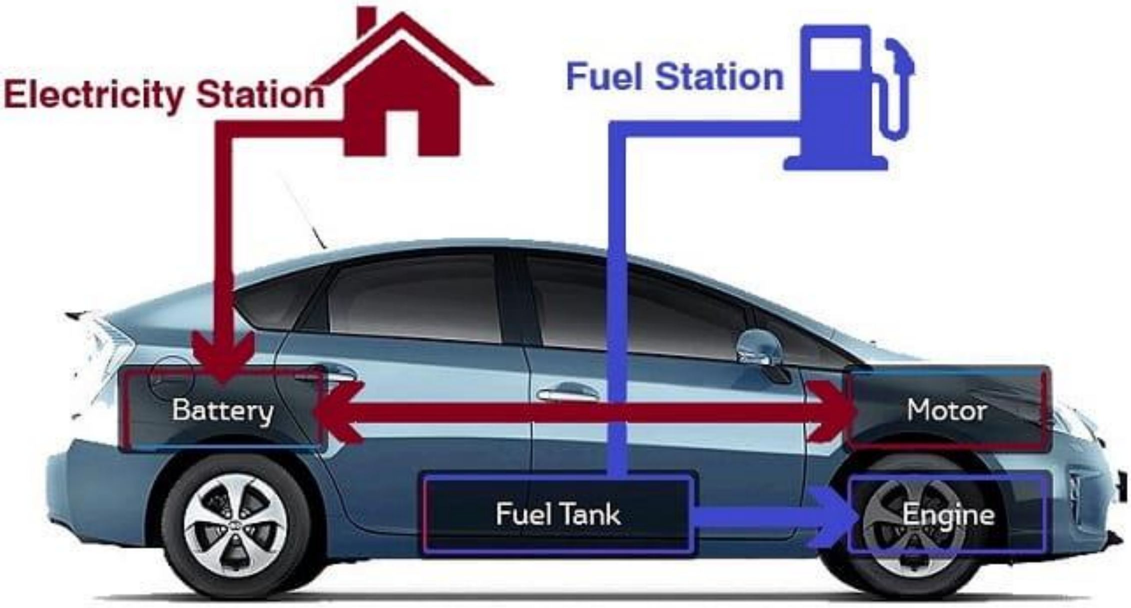

Fig: Hybrid Vehicle

In contrast to fully operated I.C. engine cars, the hybrid electrical car has batteries that provide and drive electric motors in addition to a fuel tank that supplies power to the internal combustion engine. There are several methods to pack and charge the battery. The main advantage of the hybrid electric vehicle (HEV) is that it is fuel economical.

These types of cars have lower emission rates, higher power, and better fuel efficiency than conventional vehicles. A hybrid engine provides better fuel efficiency and power than other types of engines.

When a hybrid car drives or brakes, it creates excess energy to charge the engine battery. Therefore, you don’t need any external source to charge the battery manually. Secondly, this process also helps to improve fuel range or efficiency.

A conventional hybrid car is a fully electric vehicle. These include an electric motor that drives the wheels and a battery that powers the electric motor. Then there's a completely separate petrol engine that powers the generator. Conventional hybrid cars have very small engines.

Conventional hybrid vehicles have high weight. These vehicles have to support the weight of batteries, gasoline engines, generators, and electric motors.

The conventional hybrid vehicle doesn't require as much battery power as a pure electric car, so you can save weight, but a full-size electric motor and 10-kilowatt generator weigh hundreds of pounds.

Now, we are going to study how does a hybrid car work?

Working Principle of Hybrid Car

The main purpose of hybrid car construction is to lower the combustion of fuel and lower the emission rate of harmful gases. Hybrid vehicles are powered by at least two types of energy sources.

The old hybrid vehicle had a stationary gas engine to power the generator. This generator was transmitted electrical energy to an electric motor mounted on the front wheel hub.

The latest hybrid vehicle uses a combination of electrical and fuel (petrol or diesel) power. This type of vehicle has a various number of electric motors.

A hybrid car works in the following way:

- First of all, the carburetor of the car engine sucks air from the environment and makes a mixture of the fuel-air mixture.
- The air-fuel mixture is sent to the compression cylinder of the I.C. engine.

- The compression cylinder contains a reciprocating piston.
- This piston compresses the air and fuel mixture. Due to high compression, the air-fuel mixture ignites, and power generates.
- The power produced by the engine is sent to the generator to generate electricity.
- The generated electricity is used to charge the car battery or to run the motor.
- As the power transfers to the battery, the battery stores it. This stored power is utilized to run the car when the engine is not working.

How does a Hybrid Vehicle charge battery?

It depends on the hybrid type. Most products, including plug-in and series hybrids, use a gasoline engine to generate electricity and charge the battery. Plug-in hybrids can also run-on mains electricity.

Parallel hybrids differ because they only charge the battery by absorbing additional energy and converting it into electricity. The extra energy, typically wasted when the car is idling or slowing down, is stored in the battery for later use (e.g., regenerative braking).

This “regenerative” charging is used in petrol engines and other hybrid vehicles.

Types of Hybrid Cars

Automakers use various hybrid designs to achieve maximum fuel efficiency or keep the price of the hybrid vehicle as low as possible. There are different types of hybrid cars. The hybrid car has the following major types:

1. Parallel Hybrid
2. Series Hybrid
3. Plug-in Hybrid
4. 2-Mode Hybrid
5. Mild-Hybrid

1) Parallel Hybrid

Parallel hybrid includes in the most famous types of the hybrid electric car. This design is very famous.

Parallel hybrids use both an internal combustion engine and an electric motor to produce the power and run the car. In a Parallel hybrid car, both the electric motor and I.C. engine are connected in parallel to the transmission or gearbox.

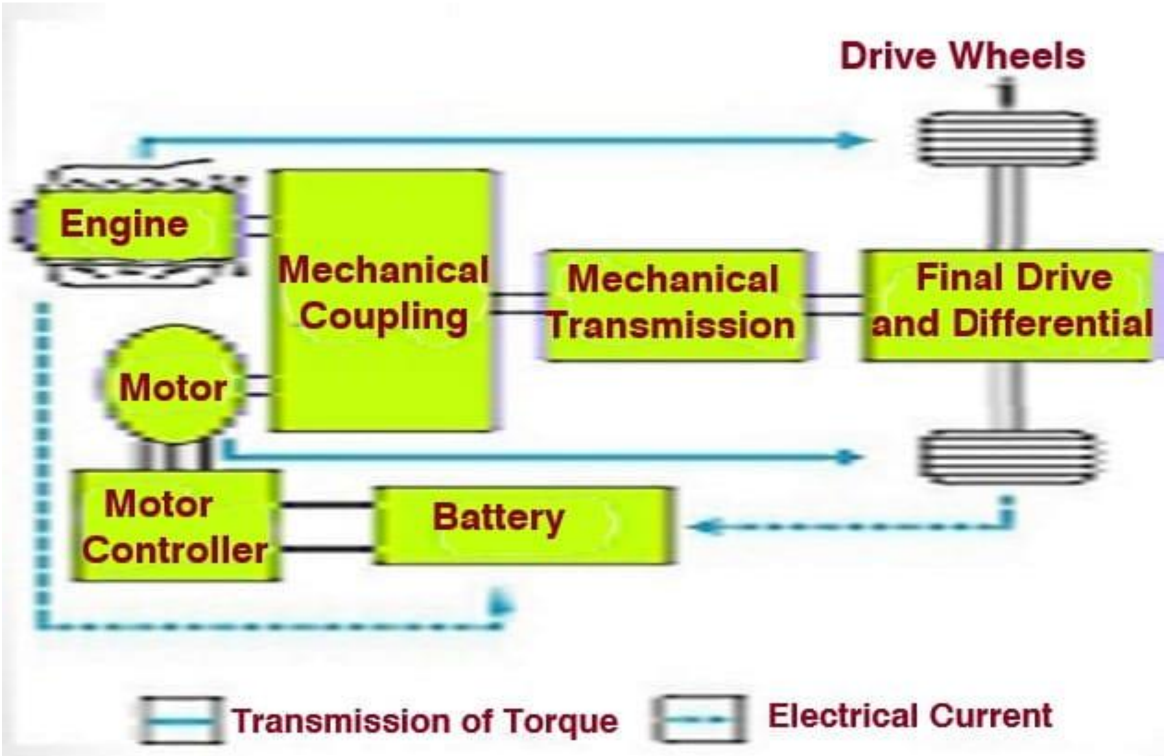

Fig: Parallel Hybrid Vehicle

The parallel hybrid uses a microcontroller to control the energy transfer process. This microcontroller determines whether the engine and motor operate separately or together.

A battery pack uses to power the electric motor, and a fuel tank uses to supply fuel to the engine. The electric motor also acts as the engine's starting mechanism. These motor shafts are connected directly to the clutch less transmission.

Therefore, when the vehicle is driven solely by the engine, the shaft continues to rotate. This allows the motor to act as a generator. The electricity generated uses to charge the battery.

Examples of parallel hybrid vehicles are the Hyundai Sonata, the Toyota Prius, the Honda Accord, Toyota Camry, etc.

Nowadays, almost all hybrid vehicles are parallel hybrids, not serial hybrid cars. The powertrain of Toyota's hybrid car is equipped with an Internal combustion (I.C.) engine and two electric motors that can also use as a generator. These electric motors charge the engine batteries. Otherwise, energy will be wasted, for example, when breaking the car.

The energy stored in a relatively small battery is sufficient to power the powertrain or drive a car for about a mile as needed. Therefore, Toyota hybrid cars can only run-on electricity; these can also run-on I.C. engines or both. However, the only source of power for cars is fuel.

2) **Series Hybrid**

The process in which the one source power is converted into the power of another one, and this power runs the car is known as a series hybrid. The vehicle works on the “series hybrid,” is known as the series hybrid vehicle.

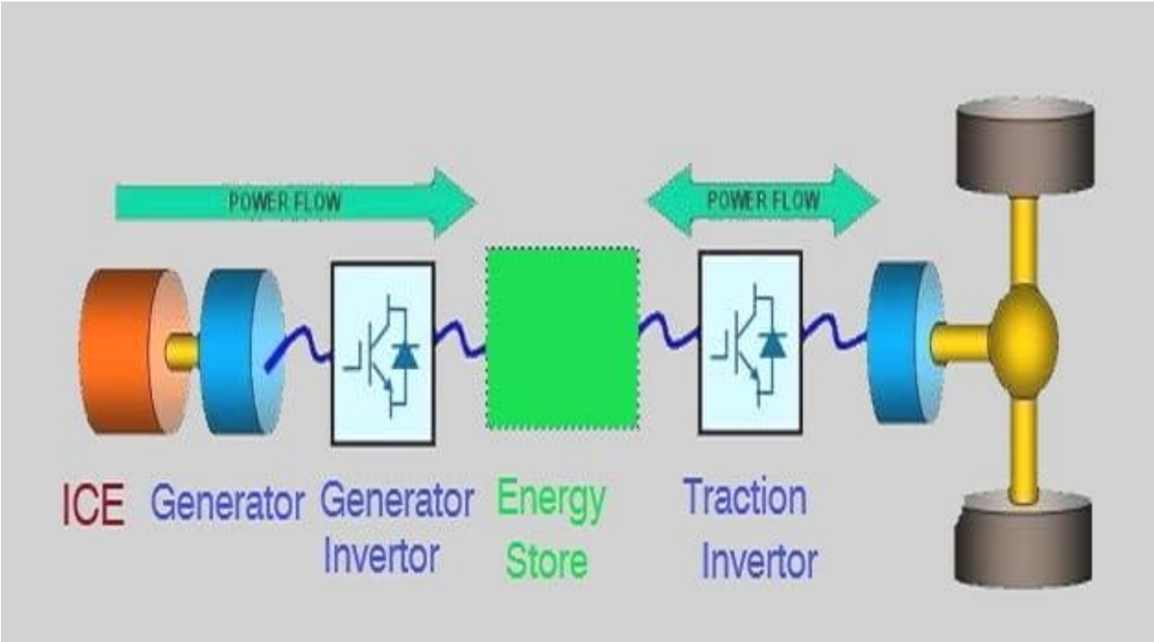

Fig: Series Hybrid Vehicle

The series hybrid car has a generator and engine in series. The generator uses the electricity produced by the engine to generate electrical power. This power is used to run the engine or charge the battery.

When the engine is not operating, the electricity stored in the batteries may utilize to move the vehicle. These cars are similar to electric cars in that the final drive is provided solely by the electric motor.

The speed of the motor can be changed simply by changing the power supply, eliminating the need for a complicated transmission system.

This system increases the engine efficiency and permits the engine to drive at the most efficient RPM regardless of vehicle speed.

The power produced during these idle situations is saved in the battery for later use. Series hybrid cars are more efficient but require a lot of energy conversion. Each of these conversions loses power and reduces the overall efficiency of the system. Another disadvantage of this series system is that it requires more parts than parallel systems. This increases the overall mass of the car.

Series hybrid power transmission systems are very popular in ships and locomotives. The nuclear submarine is an example of a series hybrid car. The nuclear reactors produce heat, which drives steam turbines, which further drive generators. The diesel locomotive is a hybrid vehicle.

Nowadays, this method is used because it is much easier to move a vehicle on electrical power than to get raw power from a nuclear reactor or a large Diesel engine. Besides, the trains run hundreds of tons of weight, and the provision of clutch-less transmission is compulsory to run a train.

3) **Plug-in Hybrid Car**

The plug-in hybrid car allows traditional hybrid vehicles to have larger batteries that need to be recharged. Typically, these hybrid cars use a 110V socket to charge the battery, just like you would with an electric vehicle.

The plug-in hybrid cars rely on internal combustion engines and can run after a full charge, significantly improving the car’s fuel efficiency. Volvo XC40 Recharge Plug-in Hybrid, Hyundai Ionis Plug-in Hybrid, and BMW 330e are examples of the plug-in hybrid electric car.

Fig: PHEV Vehicle

4) **2-Mode Hybrid Cars**

These types of hybrid design work in two distinct ways. In the first mode, it works like a normal hybrid car. In the 2nd mode, you can adapt the design to various engine requirements for a precise vehicle task.

Fig: 2-Mode Hybrid Cars

5) **Mild-Hybrid Car**

In recent years, the cost has become very high for manufacturing hybrid vehicles having high efficiency. Vehicle companies are developing new plans to bring hybrid technologies to an ordinary person.

Automotive companies have adopted a mild hybrid design to meet emissions standards and slightly improve the efficiency of the fuel without significantly increasing costs.

In the mild hybrid car, an electric motor helps the petrol or gasoline engine to improve performance, improve fuel efficiency, or both. It is also used as a starter for the automatic stop or start functions, which reduce fuel consumption by turning off the engine as the vehicle is stationary and reducing fuel use. Baleno, Ciaz, and Maruti Suzuki Ertiga are examples of mild hybrid vehicles.

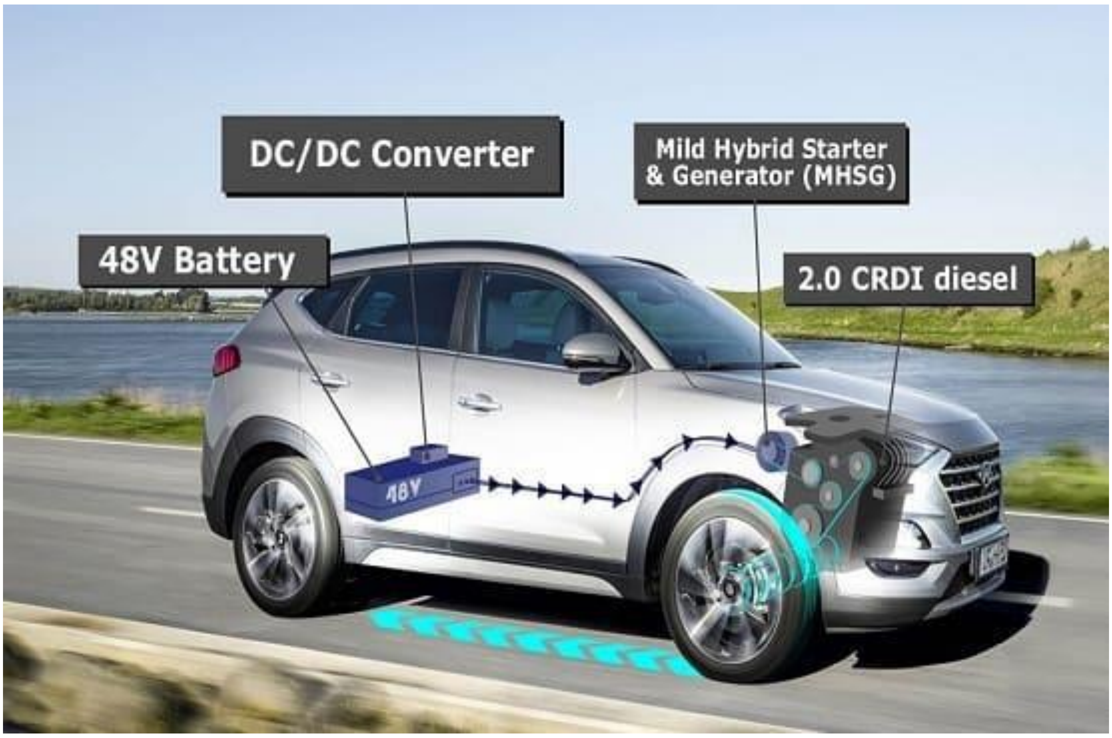

Fig: Mild-Hybrid Car

2.2 LITERATURE REVIEW

1. Khatun P, Mellor P H, Bingham C M; "Application of Fuzzy Control Algorithms for Electric Vehicle Antilock Braking/Traction Control Systems". In paper [1], author P Khatun has described the preliminary research and implementation of an experimental test bench set up for an electric vehicle Antilock Braking System (ABS)/Traction Control System. Here a low-cost test bench is used to develop fuzzy control algorithms. In the test bench, a brushless permanent magnet motor is used which is driven by a power inverter and is controlled by a DSP controller. The PM motor is connected to a three-phase induction motor which is used to simulate actual road load. Simulation studies are employed to derive an initial rule base that is then tested on an experimental

setup representing the dynamics of a braking system. Fuzzy logic membership functions are described for parameters like slip and observed load torque. On basis of the fuzzy rules set, the output torque demand function is derived. By using these fuzzy rules, the slip ratio is limited to 0.1 for dry surfaces. According to the fuzzy rules, the algorithm identifies unstable regions in the graph of torque-slip and reduces the slip. Eventually the slip stabilizes around 0.25 and the control region extends up to 0.35 for a dry road surface. The results indicate that ABS substantially improves performance and has potential for optimal control of wheels under difficult driving conditions.

2. Dixon J, Cortazar M; "Regenerative Braking for an Electric Vehicle using Ultracapacitors and Buck-Boost Converter".

This paper [2] describes a method to recover energy during braking by using a system of Buck-Boost converter and an Ultracapacitor bank. The buck-boost converter is made using IGBTs and the entire system has been tested on a Chevrolet electric truck. Using a control strategy, the [10] maximum current going to the battery, minimum and maximum voltages of the Ultracapacitor bank are set. The control strategy uses a reference table and has inputs like the state of charge of the battery, vehicle speed, load current etc. A strategy is also given which uses sensors to determine the wheel decelerations so that the converter can be used optimally to recover maximum energy. Results are shown using graphs of battery current, voltage and the capacitor bank voltage. The graphs indicate the proper working of the buck-boost converter. This designed system allows higher acceleration and proper decelerations with minimal loss of energy and minimal degradation of the battery pack.

3. Xiang Y, Xin Z; "Study of control logic for Automobile Anti-lock Braking System".

In this paper [3], to find the ideal logic principle for antilock braking, Simulink is used to create the state flow model for the ABS electronic control unit. The state flow diagram for a four channel ABS system is also charted out. The control logic uses logic threshold control method. It uses parameters like reference slip ratio and angular speed threshold to calculate the optimum braking pressure to be applied. The acceleration of the wheel is measured and plotted. When the acceleration is negative, i.e., deceleration is taking place, the logic keeps on monitoring the value till it is of lower value. When it increases, the logic detects when the wheel is about to lock up. This unstable region is detected and the braking pressure is now adjusted so that this unstable region is not encountered again and the wheel is decelerated without the wheel being locked up. A method of alternate boost pressure and decompress is employed so that the vehicle can stay in the stable region for as long as possible and the optimum braking pressure can be applied. [11]

4. Xu C, Sha L, Cheng K; "Simulation of Integrated Controller of the Anti-Lock Braking System".

In this paper [4], the simulation of a braking system is done by using an integrated controller consisting of a PID controller and a finite state machine. The parameters given to the system are wheel speed, vehicle speed, slip and braking distance. According to these parameters, the braking pressure is controlled. The drawback is that only a single wheel model is used to simulate the braking conditions. The results are compared when the slip ratio is the control parameter and when the integrated controller is used. The use of integrated controller gives a much better control over the slip ratio and the braking pressure can be stabilized to a stable value with much less time than without the controller and the braking distance too reduces significantly.

5. Piroddi L, Tanelli M; "Real time identification of tire- road friction conditions".

This work [5] aims at the real-time estimation of the wheel slip value corresponding to the peak of the tire–road friction curve, in order to provide anti-lock braking systems (ABS) with reliable information on its value upon activation. Different techniques based on recursive least squares and the maximum likelihood approach are used for friction curve fitting and their merits and drawbacks thoroughly examined. Also, optical and pressure sensors are used for measuring the brake pad pressure and working. Their output is then filtered and made sure that there is phase coherence between all signals. The algorithm selects the wheel which has the relatively fastest speed among the four wheels, i.e., the wheel which has the lowest longitudinal slip. The estimated vehicle speed is then found out according to the algorithm. Also, a comparison is made between the value of coefficient of friction μ obtained through estimation and its actual value.

CHAPTER 3

Regenerative Braking System

Working Methodology

3.1 Operation

In regenerative braking, when a car needs to be braked, the motor is rotated in the reverse direction, or if the motor is an ac motor, it is then operated in the third quadrant of operation. The effect is that the motor now acts as a generator and provides energy back to the battery. In some cases, this energy may be stored in some alternative storage systems temporarily, like capacitor bank, flywheel, spring systems etc.

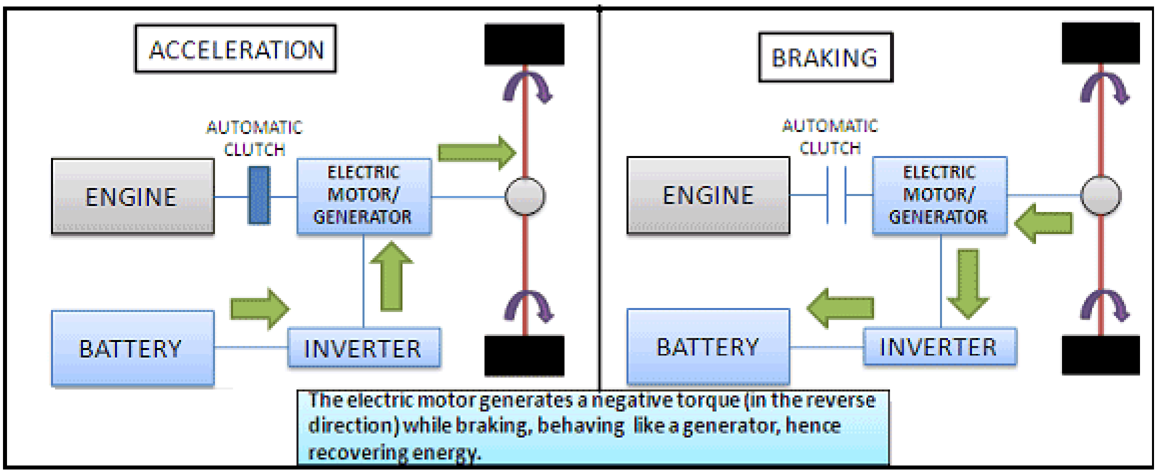

Fig: Operation of Regenerative Braking

Regenerative Braking is used in conjunction with friction brakes. In some cases, at slow speeds, the regenerative braking alone may not be sufficient to bring the vehicle to a complete halt. If the regenerative torque cannot be made high enough to match the braking torque, then the friction brakes make up the difference. Also, if the regenerative brakes fail, then the friction brakes act as [23] a backup braking system. Regenerative braking can be used in both pure electric as well as hybrid electric vehicles [17]. In hybrid vehicles, the gas consumption is reduced because of it.

The regenerative braking along with friction brakes can be used in two ways. First, the available braking power from regenerative braking can be calculated and the rest can be supplied by the friction brakes. In such a case, a microcontroller calculates such values in real time using the system parameters. The parameters involved are battery state of charge, vehicle velocity, motor capacity etc. Secondly, without using a controller, both regenerative brakes and the friction brake

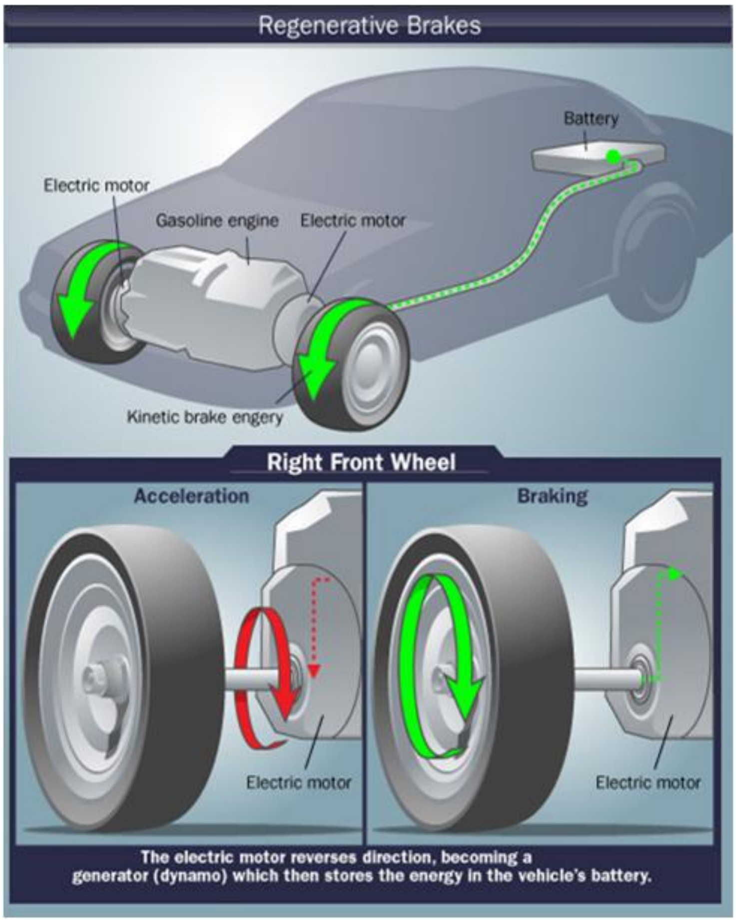

Fig: Regenerative Braking in a Hybrid Electric Vehicle

can be applied in tandem. Regenerative braking is applied to only those wheels which are driven by the motor [16]. Hence, either only front axle or rear axle can have it. The other set of wheels can have frictional brake systems. Friction brakes systems need not be conventional brakes, and systems like Anti-lock Brake System can be used along with the regenerative brakes.

When a motor is used for regenerative braking, it is reversed in direction of operation. The shaft rotates in the same direction. But as a motor it consumes electricity to generate rotation of the wheels while as a generator, it uses the kinetic energy of the rotating wheels to generate electricity to give back to the battery.

3.2 Working Methodology

This project consists of two 12-volt permanent DC motor to drive the wheel. During Regenerative action as battery have a good quality of quickly charges and discharges while braking. When we will give the supply as this wheel are rotate, on that time we will see the multi meter where we will see the voltage. The voltage is zero that means there is no voltage drop on that time. In this case the battery will go to zero volts. But when we will press the brake pedal on that moment the wheel will stop and the voltage will go to the battery for reserve and the bulb will glow.

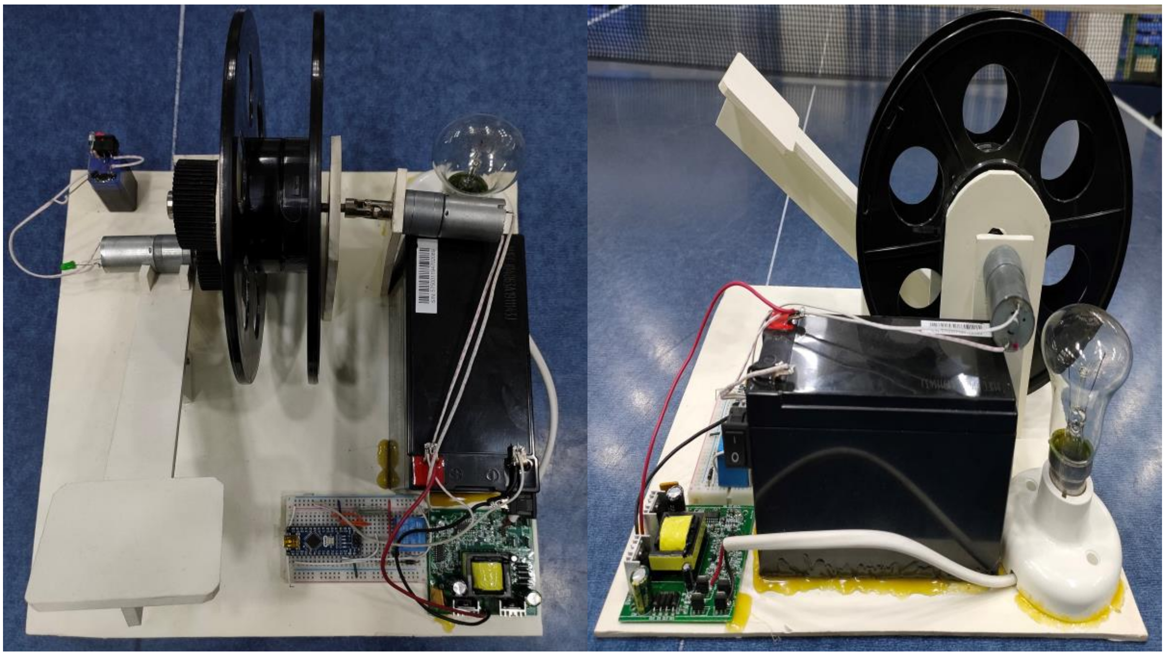

Fig: Regenerative Braking System

3.3 FABRICATION

a) Wheel

Wheel gets in motion with the help of running motor. Both motor and wheel is connected with the help of connecting universal coupling.

Fig: Wheel

b) Electric Motor

A DC motor is an electrical machine which converts electrical energy into mechanical energy. The basic working principle of the DC motor is that whenever a current carrying conductor places in the magnetic field, it experiences a mechanical force.

Fig: Electric DC motor

c) Digital Multi Metter

A digital multi meter is a test tool used to measure two or more electrical values principally voltage (volts), current (amps) and resistance (ohms). It is a standard diagnostic tool for technicians in the electrical/electronic industries.

Fig: Digital Multi Metter

d) Generator Motor

A DC motor is an electrical machine which converts electrical energy into mechanical energy. The basic working principle of the DC motor is that whenever a current carrying conductor places in the magnetic field, it experiences a mechanical force.

There are 4 major types of DC motor and they are,

- Series DC Motor.
- Permanent Magnet DC Motor.
- Shunt/Parallel DC Motor.
- Compound DC Motors.

Fig: Generator Motor

e) Arduino Nano Microcontroller

Arduino is an open-source platform used for building electronics projects. Arduino consists of both a physical programmable circuit board (often referred to as a microcontroller) and a piece of software, or IDE (Integrated Development Environment) that runs on your computer, used to write and upload computer code to the physical board.It can simply use a USB cable. Additionally, the Arduino IDE uses a simplified version of C++, making it easier to learn to program. Finally, Arduino provides a standard form factor that breaks out the functions of the micro-controller into a more accessible package.

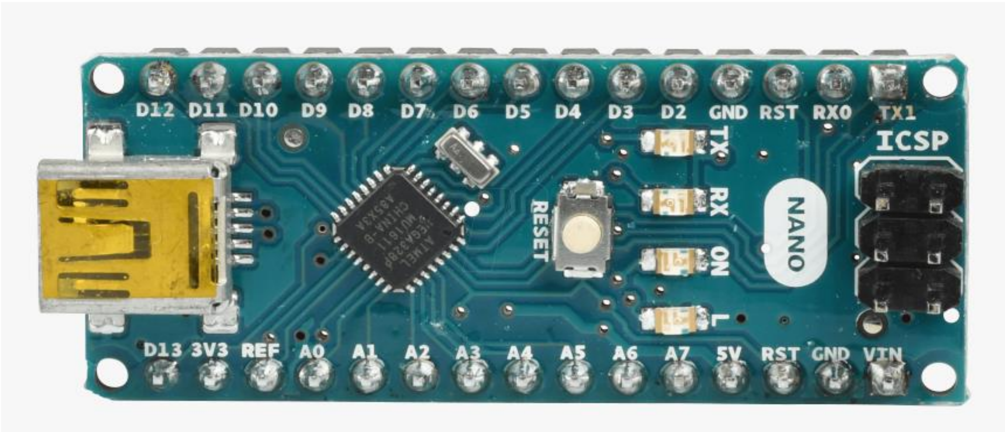

Fig: Arduino Nano Microcontroller

Program:

```
#include <SoftwareSerial.h>
int relay = 13;
char sms;
SoftwareSerial BT(2,3);
void setup()
{
  Serial.begin(9600);
  BT.begin(9600);
  pinMode(relay,OUTPUT);
}
void loop()
{
  sms = 'D';
  if (BT.available())
  {
    sms=BT.read();
  }
  if(sms=='F')
  {
    Serial.print(" SMS=");
    Serial.print(sms);
    Serial.println();
    digitalWrite(relay,HIGH);
  }
  if(sms=='S'){
    Serial.print(" SMS=");
    Serial.print(sms);
    Serial.println();
    digitalWrite(relay,LOW);
  }
}
```

f) **HC-06 Bluetooth Module**

The HC-06 is a very cool module which can add two-way (full-duplex) wireless functionality to your projects. You can use this module to communicate between two microcontrollers like Arduino or communicate with any device with Bluetooth functionality like a Phone or Laptop. There are many android applications that are already available which makes this process a lot easier. The module communicates with the help of USART at 9600 baud rates hence it is easy to interface with any microcontroller that supports USART. We can also configure the default values of the module by using the command mode.

Fig: HC-06 Bluetooth Module

g) Inverter

An inverter can be defined as it is a compact and rectangular shaped electrical equipment used to convert direct current (DC) voltage to alternating current (AC) voltage in common appliances. The basic role of an inverter is to change DC power into AC power. The AC power can be supplied to homes, and industries using the public utility otherwise power grid, the alternating-power systems of the batteries can store only DC power. In addition, almost all the household appliances, as well as other electrical equipment can be functioned by depending on AC power.

Fig: Inverter

Chapter 4

CALCULATIONS

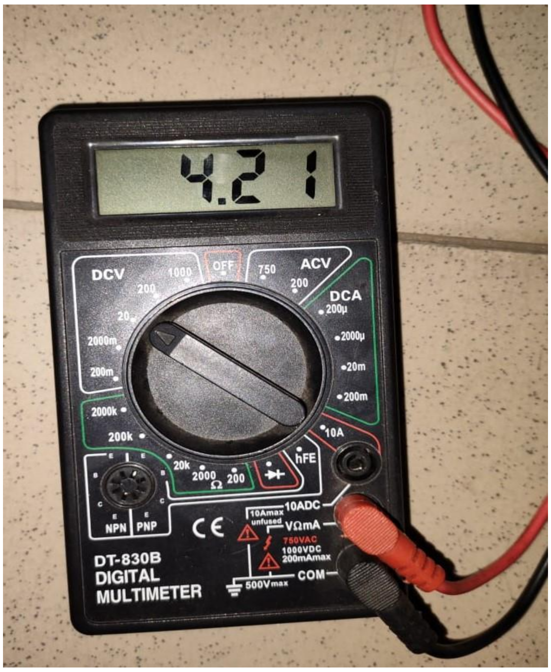

Fig: Multimeter

Relationship between power generation and braking time.

Braking Time	Voltage Generate
3sec.	4.14 v
7 sec.	4.21 v
10 sec	4.25 v
12 sec.	4.31 v

Chapter 5

CONCLUSION

FUTURE WORK

5 CONCLUSIONS

5.1 Conclusion

Regenerative braking systems require further research to develop a better system that captures more energy and stops faster. As the time passes, designers and engineers will perfect regenerative braking systems, so these systems will become more and more common. All vehicles in motion can benefit from these systems by recapturing energy that would have been lost.

The Regenerative circuit stores and returns the energy back to the battery which would have been otherwise wasted. The buck-boost converter depends on signals from the microcontroller and operates in real time so that the energy can be stored at the exact moment of deceleration and can be returned back during the few seconds of acceleration. The battery bank too charges and discharges fast so that the energy flow can be fast and efficient without much loss. This makes a battery last longer as well as allows an electric vehicle to travel further on a single battery charge i.e., the mileage of the electric vehicle increases substantially.

5.2 **Scope for Future Work**

The extension of the project work carried out here will be to test the circuits on a prototype vehicle. Slip can be more effectively measured when all the four wheels are present and braking is applied on only one of the axles. This will increase the accuracy of the braking pattern provided. Also, the capacitor bank can be replaced by Ultracapacitors when the system works on a higher voltage level. Ultracapacitors are costly but they can store 20 times the energy stored in conventional capacitors and have much less energy loss. The ultracapacitors when used in an actual electric vehicle which may be working around a 300Volt DC battery supply prove to be cost effective as well as capable of providing a superior performance.

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