Electric Vehicle Powertrain Design

A Final Year Project Report

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In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

by

Sheikh Muhammad Danish

Muhammad Adnan Warraich

Hamza Jalal

Syed Muhammad Kumail

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EXAMINATION COMMITTEE

We hereby recommend that the final year project report prepared under our supervision by:

Sheikh Muhammad Danish	00000128602
Muhammad Adnan Warraich	00000125167
Hamza Jalal	00000133385
Syed Muhammad Kumail	00000126919

Titled: "**Electric Vehicle Powertrain Design**" be accepted in partial fulfillment of the requirements for the award of **BE Mechanical Engineering** degree with grade ___

Supervisor: Dr. Jawad Aslam	____________________ Dated:
Committee Member: Dr. Riaz Mufti	____________________ Dated:

______________________ ___________

(Head of Department) (Date)

COUNTERSIGNED

Dated: ________________ _________________________

(Dean / Principal)

ABSTRACT

Electric vehicles are a step in the goal of eco-friendly transportation. EVs have zero emissions. They haven't completely reached their true potential and it is a long time till they emphatically phase out IC engines. Moreover, they have issues in regard to the disposal of batteries. However, these steps are a necessity towards the end goal.

In our project, we aim to partially replicate an IC based vehicle as an electric one, so electric vehicles can cement their place as the ultimate IC engine successor.

ACKNOWLEDGMENTS

We would like to express our great appreciation to Dr. Jawad Aslam for his valuable and constructive suggestions during the planning and development of our Final Year Project. His willingness to give us so much of his precious time is appreciated.

ORIGINALITY REPORT

We hereby declare that no portion of the work of this project or this report is a work of plagiarism and the workings and the findings have been originally produced. The project has been done under the supervision and guidance of Dr. Jawad Aslam and has not been a support project of any similar work serving towards a similar degree's requirement from any institute. Any reference used in the project has been clearly cited and we take sheer responsibility if found otherwise. Following pages show our Turnitin Originality report.

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ABBREVIATIONS

ICE	Internal Combustion Engine
EV	Electric Vehicle
HEV	Hybrid Electric Vehicle
PEV	Pure Electric Vehicle
GR	Grade Resistance
GVW	Gross Vehicle Weight
DCT	Dual Clutch Transmission
CVT	Continuous Variable Transmission

NOMENCLATURE

M	Mass of vehicle
r	Vehicle radius
C_R	Co-efficient of rolling resistance
g	Gravitational acceleration
C_D	Drag Coefficient
A	Vehicle Frontal Area
Bat_v	Battery voltage
Bat_c	Battery capacity
Ø	Road Incline

CHAPTER 1: INTRODUCTION

From the very beginning of the world, man has strived to look for and present better versions of every invention done by the very previous generation. Be it be a steam engine or a simple invention of wheel which revolutionized the world and changed the future completely. Wheels, for example, were first being used as pulleys only to lift goods up. Later, they started to make their way under carts and carriages to transport goods from one place to another. Ultimately, they saw their use in travelling when they were finally put under vehicles.

The Automotive Industry

Before the 20th century, the automobiles were really a novelty, and everyone aspired to get oneself in loop with this majestic invention. The automobile industry really took off in 1920s. Later, the mass globalization of automotive companies helped the invention getting global recognition. Slowly and steadily, the automobiles not only got more efficient but also more affordable for common people and the era of everyone owning their own personal vehicle started with the start of 21st century.

Advancements in Automotive Industry:

The automotive evolution started in 1700s – 1769 to be exact when the first steam-powered vehicles were manufactured. These slowly progressed to the advent of vehicle powered by Internal Combustion (IC) engines in 1806. Modern day gasoline vehicles started being manufactured in 1885. These were being widely used and manufactured when environmental engineers started to realize the harmful effects of emissions that came along this revolutionary invention and hence the invention of a vehicle with low to zero emissions became the center of interest of modern-day vehicle engineers. The future of automobiles will focus on low and zero emissions, which takes us back to the beginnings of transportation (e.g. horse powered chariots), only this time with much more horse power. This takes us to talk about our Final Year Project's fundamental interest.

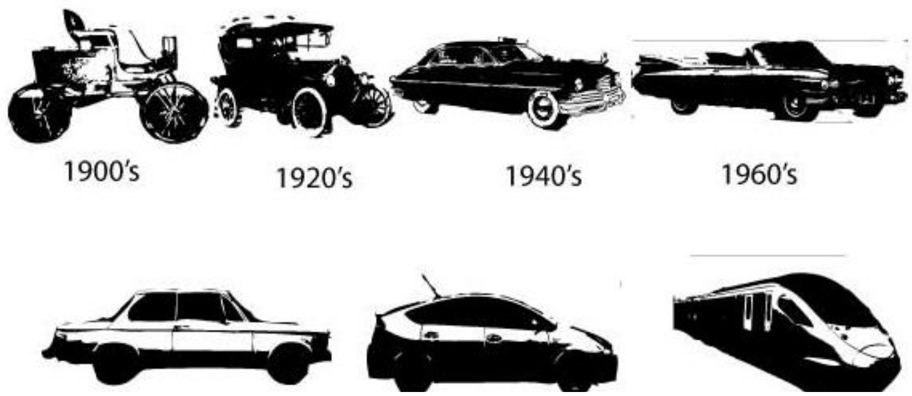


Figure 1: The evolution of automobiles

The Electric Vehicles (EVs)

The electric cars came to existence in mid-19th century but they were quickly looked over in the already vast advanced IC engine vehicles with much more power. However, as time passed by, an emerging interest in these vehicles started again when a need for powerful but at the same time those vehicles was felt which contributed in low to zero gaseous emissions.

This is where electric vehicles come into play. EVs are ideal vehicles when emissions pose a problem but like everything else, these vehicles which save us at a place will pose a problem at another. Some of the cons, an electric vehicle has, are:

1. Mileage is the biggest issue with EVs. Since it depends on the battery being used, more mileage means bigger battery which implies more investment and weight
2. Weight: Bigger battery increases the weight along with the expenses. More weight compromises efficiency and hence range

Motivation, Problem Statement and Objectives

All the discussion presented above is the root of our motivation towards our senior year project that is,

"How to come up with an electric vehicle design which gives the best mileage given its weight?"

This statement is a very vast one which had to be broken down to fit our project's objectives. So, we presented another, more convenient statement which aligns with the scope of our study as well as fulfils our mission objectives:

"How can we design an optimised powertrain for an electric vehicle for the best performance considering the existing developed battery technology."

The key objectives that we wish to achieve by the end of this project are:

1. Comprehensive knowledge of various components that will be installed on our final prototype
2. Development of a mathematical model of our powertrain which gives us a set of performance parameters we would want to attain in our prototype
3. An assembly of various components which would be our final prototype, achieving our desired performance parameters

CHAPTER 2: LITERATURE REVIEW

Electric Vehicle and its types

Electric Vehicles (EVs) are a very promising alternative to conventional Internal Combustion Engine powered vehicles which run on fossil-fuels. Like all machinery, the term EV itself is a very generic one and it can further be broken down if we classify the specifics. An EV can be of the following types:

1. Battery Electric Vehicle (BEV)
2. Hybrid Electric Vehicle (HEV)
3. Plug-in Hybrid Vehicle (PHEV)
4. Fuel Cell Electric Vehicle (FCEV)

The electric vehicle of our interest is BEV or PEV (pure electric vehicle). We'd be referring to the same during this report.

BEV Architecture

Battery Electric Vehicles (BEVs) have the simplest layout. The figure below shows a block configuration of this type of electric vehicle. The powertrain starts with a battery which is the source of power for the electric motor. The electric motor is then connected to a gear drive which alternates the speed and torque required according to the load. This torque is transported through means of shafts and differentials to the fly wheels. This description of the BEV is a very simple and to the point, but practically it has many more complex mechanisms, for example the conversion of DC to AC from battery. We'll keep building on those as we progress through this report.

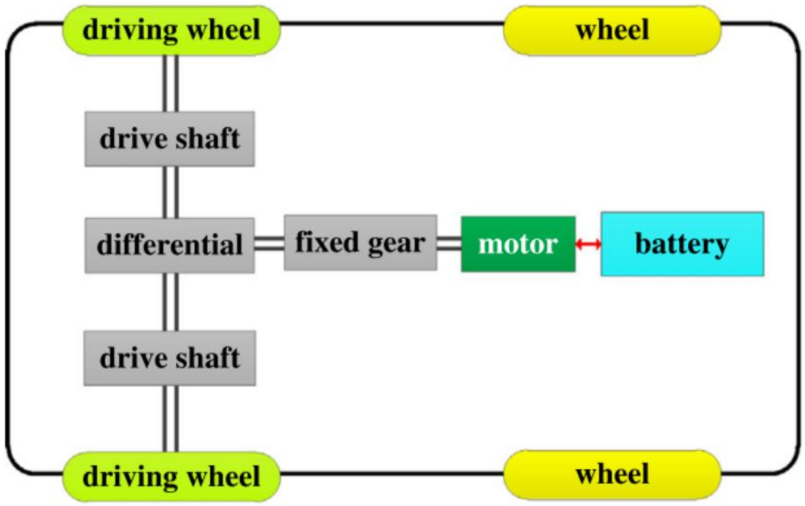


Figure 2: Configuration of an electric vehicle

This power train does not have a clutch because it is fixed gear which essentially means that this does not have a multiple speed gear box so there is no need to shift the gears, hence no clutch. This is just one of many architectures being employed in the EVs commercially available for consumers. Multiple structures can be come up with by tweaking in different ways. Now, we'll move on and talk about different components that comprise an EV's powertrain

Electric Vehicle Powertrain Components

A powertrain itself is self-explanatory, that is, it is a series of components coupled together to reinforce each other and ultimately provide the propulsion to the vehicle. The components of a powertrain are as follows:

Battery

A battery electric vehicle (BEV), pure electric vehicle, only-electric vehicle or all-electric vehicle is a type of electric vehicle (EV) that uses chemical energy stored in rechargeable battery packs. BEVs use electric motors and motor controllers instead of internal combustion engines (ICEs) for propulsion. They derive all power from battery packs and thus have no internal combustion engine, fuel cell, or fuel tank. Rechargeable batteries used in electric vehicles include lead–acid, Ni-Cd, nickel–metal hydride, lithium-ion, Li-ion polymer, and, less commonly, zinc–air and molten-salt batteries. The most common battery type in modern electric cars are lithium-ion and Lithium polymer battery, because of their high energy density compared to their weight. The amount of electricity (i.e. electric charge) stored in batteries is measured in ampere hours or in coulombs, with the total energy often measured in watt hours.

Electric Motor

Electric vehicle evolved primarily from the existence of an internal combustion vehicle by replacing ICE and fuel tank with an electric motor and a battery while keeping back all other components. Some disadvantages for example heavy load, lesser flexibility, and performance degradation caused electric vehicle using this type of use out of. Modern electric vehicle is built based on the original body and frame. The unique structure which it is satisfies what is required of an electric vehicle and makes use of a electric propulsion.

An electric motor is the heart of an electric motor – the driving force of it. It is analogous to an engine in an ICE vehicle. Electric Motors can deliver a wide range of RPM and they can delivery their maximum torque over this range which is a significant advantage of using this vehicle over their counterpart ICE vehicles. Here again, there are a lot of options one can opt for while choosing an electric motor. There are DC as well as AC electric motors. DC motors generally cost lesser than the AC ones, are generally available in the local market and can be installed easily.

Most commonly used electric motors are:

Series Wound Electric Motor

A series-wound electric motor can provide high torque however these can't be used under varying load when constant speed is required. Essentially these types of motors are employed in applications where they are always loaded so that their proper use can be found.

Permanent Magnet DC Motor

These are also one popular type of electric motors. These are similar to brushed DC motors. Like all brushed DC motors, PM DC motors are noisier and create radio interference because these do not have a series of winding which acts as a natural filter, unlike a series-wound electric motor.

Induction Motors

A 3-face AC induction motor is the expensive kind of electric motor, and if price is not taken into notes, is the best of all for electric vehicles. They have one similarity with the DC motors, that is, these use the same DC batteries as DC motors, but they have inverters in between the battery and motor which transform DC into AC.

Brushless DC Motors

Brushless DC motors have a huge advantage over brushed motors because of their higher power to weight ratio. Furthermore, they have higher speeds and can be controlled electronically.

Transmissions

Like all other types of vehicles, EVs require a mechanism to properly transport power which is to be delivered to the wheels. All the transmissions which are used in ICE vehicles cannot be used in an electric vehicle due to the inevitable interruption in torque which essentially kills the innate smooth drive of an EV. The goal is to achieve an economically and dynamically balanced EV with smooth transfer of power throughout.

The principle types of transmissions employed in an Electric Vehicle are:

1. Single Gear Reduction
2. Multi-Speed dual clutch transmission (DCT)
3. Continuous Variable Transmission (CVT)

The comparison and the decision on what transmission to use in our model is given in the later section.

Use of CVT Instead of Conventional Transmission

The purpose of any transmission is to translate engine performance into vehicle performance. A transmission accomplishes this task by providing a variety of gear ratios between the engine crankshaft and the output axle of the vehicle. Each gear ratio will result in a different vehicle profile of speed and torque while the engine operates at the same speed or range of speed. The goal of the transmission is to allow the engine to operate within an ideal state of power production, and to apply this power effectively to the track using the appropriate gear ratio.

As the gear ratio increases, the rotational speed or angular velocity of the output axel increases in relation to the angular velocity of the engine crankshaft.

The conventional four speed transmission in Figure above shows the rise and fall in engine speed between 6000 and 11000rpm as each gear exchange occurs and the vehicle increases speed. For a conventional transmission, the fluctuation in engine speed at each gear exchange is used to facilitate fluid gear transfer. As vehicle speed increases and gears are exchanged, the slope of engine speed and vehicle speed at each gear is different. Each gear and respective slope represents a different ratio of gain in vehicle speed per gain in engine speed. It is this change in slope that makes each gear useful by producing a different range of vehicle speed and production of torque.

A continuously variable transmission (CVT) is a light weight, gear reduction system that utilizes a few regulatory mechanisms to achieve the same end as a conventional automatic transmission. The comparative size and complexity of a common CVT system is shown below.

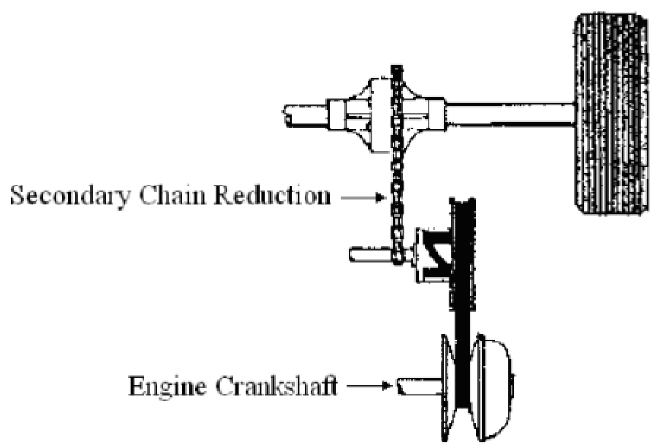


Figure 3: CVT configuration

As can be seen in Figure the CVT is a compact system and as will be described, it does not require the use of bulky gear sets or as many components as in the conventional transmission. A CVT system is comprised of two conical pulleys and a belt. As the sheaves of each pulley move closer or farther away from one another, their conical shape causes the belt to rise and fall between the sheaves of each pulley. Depending upon the state of the belt within each pulley, the active gear ratio is changed. Instead of switching between bulky fixed gears which only supply a limited number of gear ratios, the CVT pulleys create a continuous exchange of gear ratios by constantly altering the state of the belt between them. This provides a range of gear ratios limited by the pulley diameters and every possible gear ratio that is provided within that range is available for use. The regulatory mechanisms that allow for control of the pulley diameters include engine speed, flyweights, two springs, and a torque feedback mechanism called a helical torque ramp. When these mechanisms work in concert, they act to increase vehicle speed fluidly while maintaining engine speed at a single value instead of fluctuating within a single power band. This feature of engine speed maintenance is possible due to the continuous and more inclusive variety of gear ratios that the CVT offers.

Another possibility is that a CVT can be used to achieve the best automobile performance by permitting the engine to revolve at the RPM at which it produces the peak power. This is normally higher than the RPM that achieves peak efficiency. The use of CVT makes the engine to go from an idle to a pre-programmed rpm immediately, so the engine input is constant and then varies the output speed for smooth, seamless acceleration. CVTs enable power application without any jerk.

Advantages of CVT

1. CVTs provide unlimited gear ratios and improved performance.
2. Pulleys and a belt inside the CVT seamlessly change the gear ratios without any “shift shock” or delay.
3. The infinite ratios help in maintaining a steady cruising speed, reducing the fuel emissions and thus improve fuel economy.

4. Due to its ability to change the ratios continuously, a CVT helps to keep the engine in its optimum rpm range, thereby increasing the fuel efficiency.
5. The 2012 model of the Honda Jazz sold in the UK actually claims marginally better fuel consumption for the CVT version than the manual version.
6. CVTs provide quicker acceleration than a conventional automatic.
7. A key advantage of a CVT for a manufacturer is that its production costs lesser than a conventional multispeed automatic because it uses fewer parts.
8. CVT eliminates the gear shifts of a manual transmission and the accompanying rise and fall of engine speed.

Limitations of CVT

1. CVTs use steel metal belts, which have less torque transmitting capacity and thus a CVT cannot be used in heavy vehicles. Its application is limited to small vehicles.
2. Friction between the belt and the pulley causes greater wear.
3. The transmission fluid is a little expensive.

Optimum RPM Range

An automobile engine runs at its best efficiency at a certain Revolutions Per Minute (RPM) range and it is the transmission's function to make sure that the power is delivered to the wheels while keeping the engine speed within this optimum range. The transmission accomplishes this through various gear combinations. In addition to the various forward gears, a transmission also has a Neutral stance which disconnects the engine from the drive wheels, and the Reverse stance, which causes the drive wheels to turn in the opposite direction thereby reversing the direction of the car.

CHAPTER 3: METHODOLOGY

Our basic purpose is to achieve the same parameters using an electric vehicle drivetrain as that can be achieved with an internal combustion engine drivetrain. For the purpose we started with the literature review of the components of an electric vehicle that can possibly be a part of our final drivetrain. We researched about the latest technology being used that can give us a better performance overall. The focus was on which motor to be used and whether it would be efficient to work with a continuously variable transmission or not. These questions would only be answered if we would know what requirements for the drivetrain are what the output that we are trying to achieve is.

So firstly, we specify what we are trying to achieve from an electric vehicle powertrain which we want to use instead of an internal combustion powertrain. There are three things that are achieved from any drivetrain and those three include:

1. Top speed
2. Grade-ability
3. Acceleration

We chose the parameters of top speed and grade-ability that we will try to achieve from our drivetrain. These two will be explained in detail below:

But the question still remains what top speed and what gradeability is that we want to achieve. For this we need to set some physical parameters so that we are able to use them as a standard to make use of in our calculations.

We decided to use an All-Terrain Vehicle (ATV). We are using an ATV because ATV is one running example of an internal combustion engine. We chose an ATV because it was one vehicle that we could compare our results too and that we could cover keeping in the domain of the scope of our project and keeping in mind the financial constraints.

ATV range from small scale to a large scale. ATVs can be found which run from a top speed of 20 kilometers per hour to a maximum speed of 128 Kilometers that can be found in the market. They vary in cost from a few hundred dollars to even ten thousand dollars. We kept the top speed to be a maximum of 50 so that we were able to design a midrange ATV. Also the gradeability was chosen to be 40 percent instead of 50 percent of usual practice because we were able to get components that lied within our financial constraints.

We took the datasheet of a midrange ATV to find values of some of the fixed parameters that we needed to set constant so that we were able to use them in our calculations. They are listed below in the table:

Table 1: Vehicle Parameters

Parameters	Values
Mass	100kg
Frontal area	1.024 m^2
Rolling friction coefficient	0.016
Tire radius	0.254m
Drag coefficient	0.28

We are taking the mass of the whole assembly to be a hundred kgs and the frontal area rolling friction coefficient and tire radius and drag coefficient is taken from the available source.

The main constraint lies with the power source which is battery in our case. So, we are limited with the battery usage. We cannot use a battery greater than 48 volts or some as it would increase the cost and the weight. Also, to power the same amount of weight as that of an internal combustion engine, it would require a very large battery pack. The added weight and cost would outweigh the usefulness of using an electric vehicle drivetrain for increasing the efficiency. The efficiency of a electric motor is always greater than an IC engine.

We used the relations derived in the research papers that shall be give us the required parameters of the motor and gear ratios that we need to have to have in our components that is an electric motor and a CVT to be able to obtain the desired output parameters.

Gradeability:

Gradeability plays a significant role in determining the engine (or the motor in our case). Gradeability is defined as the angle of a slope that the given vehicle can successfully traverse. It usually entails the maximum angle that the vehicle can overcome. It has a drastic effect on the parameter calculations. It is usually expressed as a percentage. So 1% gradeability means that the rise over run ratio is 0.01.

A gradeability of 100% usually entails a slope of 45^{o}.

This is also calculated in terms of grade resistance, which is expressed as follows:

$$GR[lb] = GVW\ [lb] * \sin(\alpha)$$

Where:

GR= Grade Resistance

GVW= Gross Vehicle weight

α= slope in degrees

This grade resistance will be incorporated in the calculation of the tractive force.

Top Speed

The top speed is another factor that is decided by the designers in the beginning. The speed varies depending upon the demographic, the manufacturers aim to sell it to.

Our course of action was to achieve the same top speed as the ATV we had decided to implement electrically. That meant a top speed of 40 kph.

The top speed is used to calculate the acceleration force. Consequently, the time required by our vehicle to achieve that speed for something we could control. Ideally, we could have the same acceleration as the original ATV. But this was one parameter that we decided to tinker with. This was unavoidable, given our meagre resources and even limited machinery available in the market. We had a very tight financial restraint regarding the scope of our project; and what we set to achieve. Another hurdle was the lack of relevant machinery available in Pakistan. Our search for a BLDC at college Road led us to the conclusion that procuring it from abroad was inevitable. The same was the case for CVT.

Ali Express was our clear-cut option. But the haphazard devaluation of the Rupee was a great impediment. Couple that with the Shipping cost and we had found ourselves in a financial bind.

Aside from the financial fetters, Ali Express had a rather limited catalogue of the motors that could work in our conditions; and even more limited choices when it came to CVTs.

So, the logical choice was to sacrifice on some parameters in order to develop the prototype

Instead of compromising on gradeability and top speed, we reached a consensus to compromise on acceleration.

This gave us convenience in arriving at a motor that was comparatively easily available. We started off by setting up the acceleration the same as that of the ATV. From there, we changed it value on a trial and error basis, till we arrived at a favorable position.

Why BLDC?

There were a couple of competitors when it came to decide on the type of Electric motor.

1. Brushed DC Motor
2. Brushless Dc Motor
3. Induction Motor

A thorough comparison of the three types was done to decide on which motor best suits our needs.

Brushed DC Motor

1. Brushed DC motors are commutated mechanically.
2. Consequently, they are prone to wear and need regular maintenance.
3. The motor itself and its controller are cost effective.
4. But they are less efficient, which means a greater stress on the batteries.
5. They can achieve large torques at relatively low speeds.
6. This means they are suitable for traction applications.
7. Heat removal poses a problem due to the windings on the rotor.
8. Friction between brushes and commutators impedes the maximum speed.

Induction Motor

1. They are commutated via inverters.
2. Operate at higher voltages, which means a bigger and more expensive battery pack.
3. They are also prone to heating problems.

4. The motor itself is cheap but inverters are costly.
5. They have a complex control system which results in difficulty in speed control.
6. Efficiency drops starkly at low loads.
7. Furthermore, one of their greatest weakness is low starting torque.
8. So, they are not a good fit for applications like traction and handling loads.
9. Lower efficiency compared to BLDC Motor
10. Power density is also low

Brushless DC Motor

Commutated electronically via inverters, with windings located on the stator and permanent magnets on the rotor

1. Small
2. Light weight
3. Easier maintenance
4. Greater power density
5. Easier circuitry
6. Easier control system
7. Simpler heat rejection due to windings on stator
8. Less heating due to effects of eddy current

Below is a table that summarizes the above debate of the choice of the motor

Table 2: Comparison of Motors

Index	DC Motor Drive	IM Drives	PM BLDC motor drives
Efficiency	2	4	5
Weight	2	4	4.5
Cost	5	4	3
Total	9	12	12.5

This table quantifies the various advantages and disadvantages of each motor. The three factors we felt were the most essential were compared.

BLDCs were a bit costly, but they made up for that by their superior efficiency and weight.

Hence BLDC was the clear-cut winner

Why CVT?

Once the motor was decided, the next step was to determine the transmission system to go along with it in the drive train.

The four basic types of transmission are as follows

1. Manual
2. Automatic
3. Continuously Variable Transmission (CVT)
4. Semi-automatic

A direct drive assembly could also have been opted. In this arrangement, the motor is coupled directly with the differential. This simplifies the arrangement, but was not adopted because of the following reasons:

1. During a jerky journey, the system doesn't operate at the desired level of performance
2. At low speeds, this arrangement leads to very low efficiency. Hence drains the battery quicker.

We chose CVT as our mode of transmission due to the following reasons:

1. CVT allows the motor to operate in their highest efficiency region at a given value of torque and RPM.
2. Smoother running

What exactly is a CVT?

CVT is a type of transmission that has a range of gear ratios that it can adopt. The gear ratios are usually changed centrifugally.

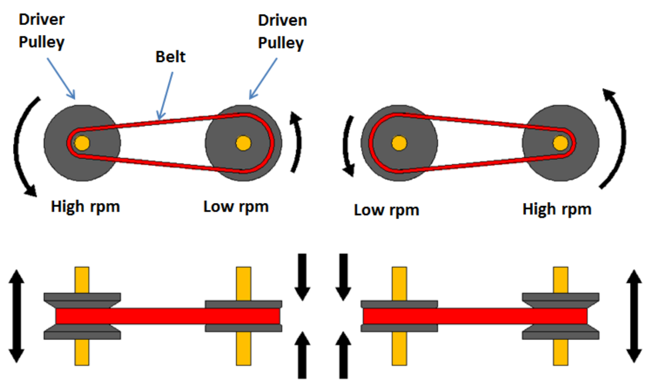


Figure 4: CVT configuration

Regarding the CVT, we have contacted a number of vendors and are in the process of deciding.

After undergoing the calculations, we conducted a thorough search of Ali Express to find the right motor. We found one with the right voltage, RPM, power and current specifications. However, it did not satisfy the torque criteria. Unfortunately, this was the motor that came closest to our requirements.

We contacted the vendors and asked them if they had something with our desired torque specifications. Their reply was that they could manufacture a customized motor for our requirements.

However, they demanded additional money for the endeavor. This was a deal breaker for us and we couldn't pursue the matter further.

To overcome this hurdle, we had to design a gearbox that could give us the required torque; which was initially supposed to be directly provided by the motor itself.

Gear Box

Gearbox is a mechanical entity used for torque increase/decrease by decreasing or increasing speed ratio. This is done by essentially changing the number of teeth. It entails multiple gears with one of the gears driven by the motor. The output speed of the gear box decreases with increase in gear ratio.

Essentially, another part had to be incorporated in our design of the prototype.

The calculations of the gear box can be subjected to changes depending upon which gear boxes are available in the market.

CHAPTER 4: RESULTS AND DISCUSSIONS

Electric Motor Selection

The motor was selected based on two requirements:

1. Torque
2. Power

Which were calculated based on 2 modes of operation, i.e.

1. High torque and low speed, for grade climbing
2. Low torque and high speed, for high speed

Now we move onto deducing and presenting results. The figure below explains the process we followed to calculate the parameters we desire.

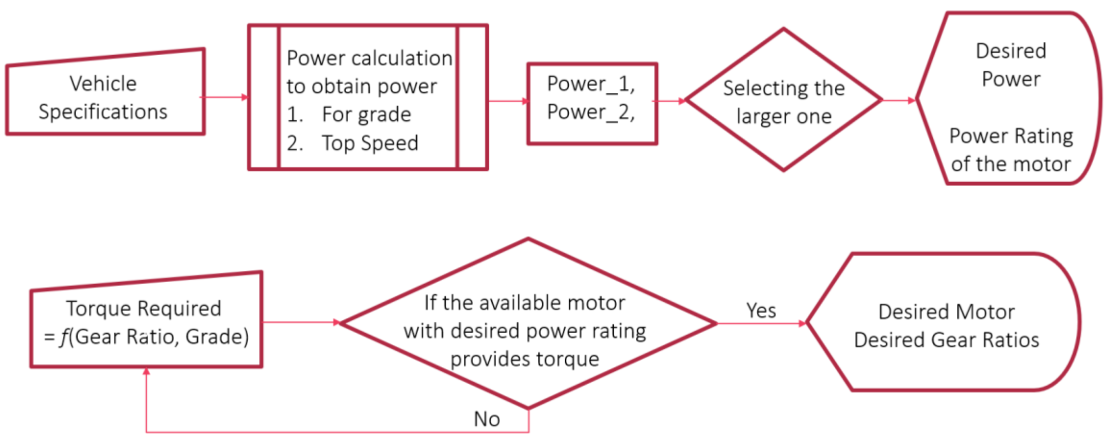


Figure 5: The Design Process

The vehicle parameters are,

Parameters	Values
Mass	100 kg
Frontal Area	1.024 m^2
Rolling Friction	0.016
Tire Radius	0.254 m
Drag Coefficient	0.28

Table 3: Target Parameters

Parameters	Values
Grade	40%
Top Speed	50 Km/h

For grade climbing, the torque required is given by:

$$T_{motor\_max} \geq \frac{(mgC_R \cos \emptyset \max + \frac{C_d A}{21.15} u^2) r}{n i_g} \quad (1)$$

And power is formulated as,

$$P_{motor\_\underset{grade}{\max}} \gg \frac{\left(mgC_R \cos \emptyset + mg \sin \emptyset + \frac{C_D A}{21.15} u^2 \right) u}{3600n} \quad (2)$$

Lastly, top speed is calculated with the formula:

$$P_{motor\_\max\_v} \gg \frac{\left(mgC_R \cos \emptyset + mg \sin \emptyset + \frac{C_D A}{21.15} umax^2 \right) umax}{3600n} \quad (3)$$

Gear Ratio Selection

The maximum grade is given by:

$$\gamma_{Max} = \frac{r_t M_v g(C_r \cos \emptyset + \sin \emptyset)}{T_{EM} n_{PT}} \quad (4)$$

For top-speed,

$$\gamma_{speed} \leq \frac{3.6(2\pi r_t N_{max})}{60 V_{max}} \quad (5)$$

We used the above given formulae and ran simulations on MATLAB with the decided vehicle parameters and achieved the following results:

Parameters	Values
Motor Power Rating	2000W
Motor Torque Rating	4 NM
Gear Box Reduction	03:01
Final Drive Reduction	3.5:1

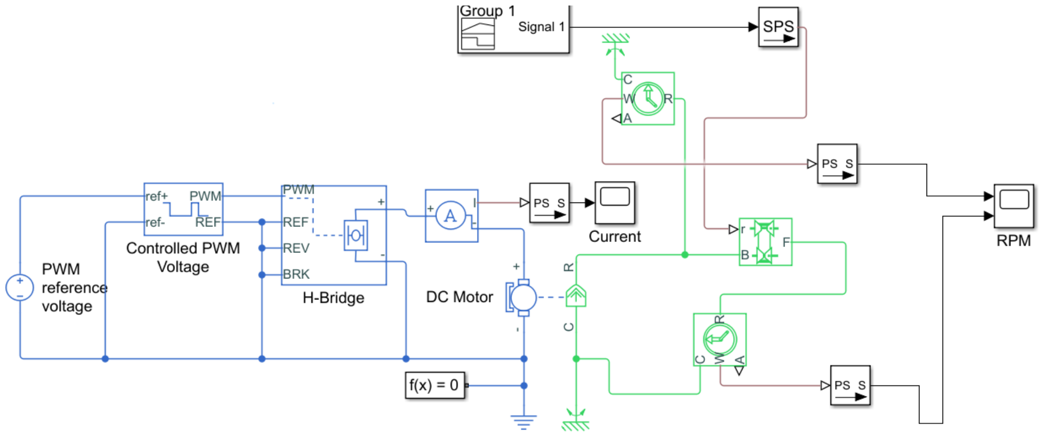
Table 4: Motor Specification

Using a CVT with gear ratio 0.84 ~ 3.28,

Modelling and Simulation

We used MATLAB SIMULINK to develop a mathematical model of our design and ran our model to obtain some output curves. Two curves were obtained, that are,

Figure 6: Mathematical model of the powertrain



1. The first graph indicates the effect on the motor speed with and without the coupling of the CVT with respect to time
2. The second graph indicates the variation of input current with respect to time

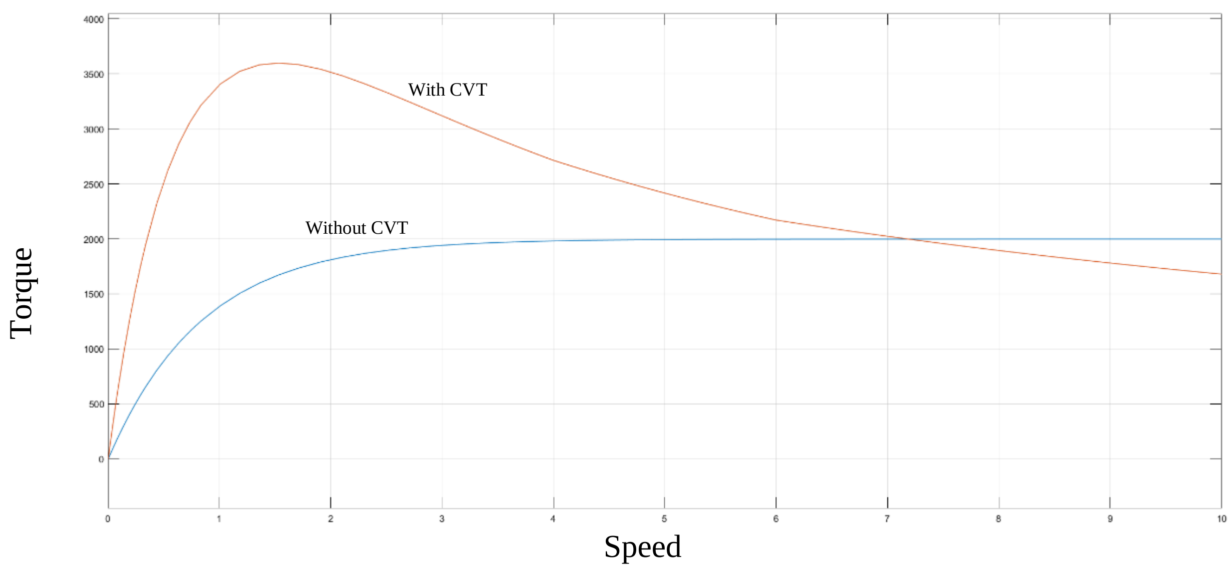


Figure 8: Variation of Motor Speed with and without CVT

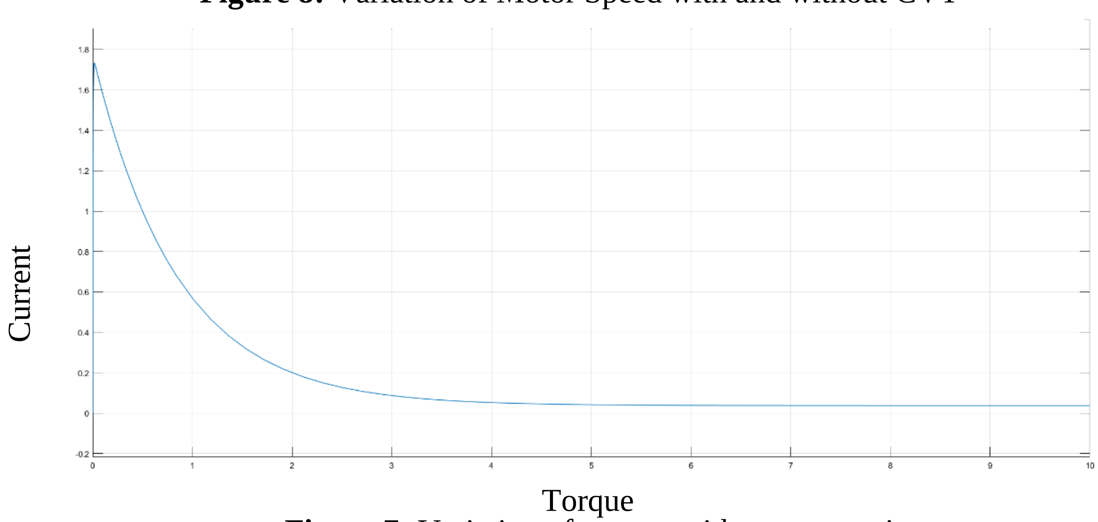


Figure 7: Variation of current with respect to time

Computer Aided Design (CAD)

After the carrying out of simulations, we moved onto developing our desired prototype with the help of computer. We used SolidWorks to carry out our design process.

The figure below shows how are final prototype would look like sitting on a table. The assembly starts with a battery (not shown in the figure) which powers the electric motor.

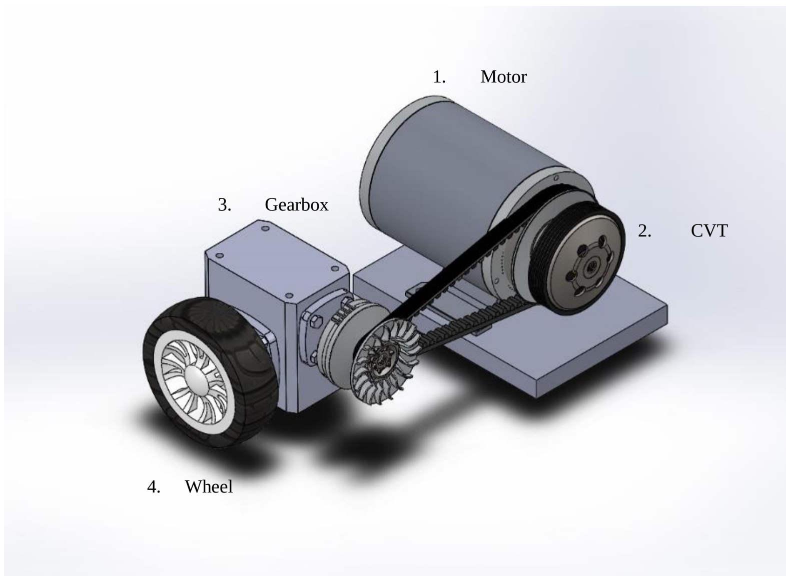


Figure 9: Drive train CAD model

The electric motor is coupled with a CVT like shown in the figure. The CVT plays the role of transmitting the torque from the motor to the wheel. There is one more component between the wheel and the CVT, that is, a gear reduction mechanism. This is essentially to scale our torque from the motor (4 Nm) to a much larger value (~120 Nm). This would be the value delivered to the wheels. We would carry out the procurement of the components assemble them on to the bench. Finally, the testing would be done, and the relevant comparisons would be carried out.

CHAPTER 5: PROTOTYPING AND TESTING

The Final Assembly

As previously mentioned the motor opted was Brushless DC Motor (BLDC). This choice was made after considerable literature review. Along with consciousness of our requirements and parameters. After a thorough market survey, we concluded that the best route is to order the motor via AliExpress.

The motor ordered was KUNRAY MY 1020. It is a 60 Volt, 2000-Watt Motor.

The motor was ordered on 19th February and reached us on 10th March. The contents of the package were as followed:

1. **BLDC Motor**

Rated RPM: 4600 Rpm

Rated Current: 33A

Figure 10: BLDC Motor

2. MOSFET Motor controller

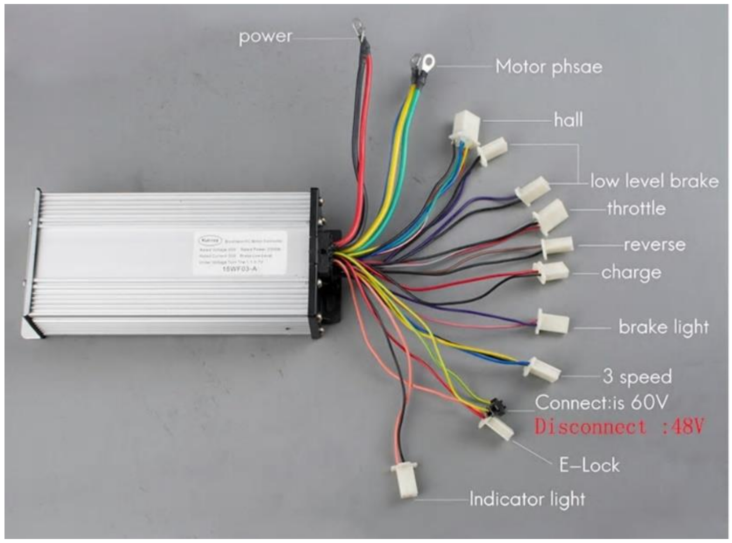
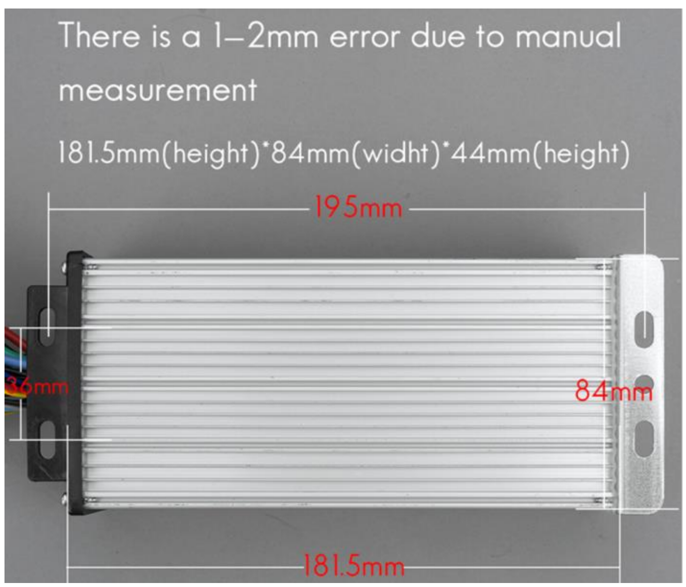


Figure 11: Motor controller

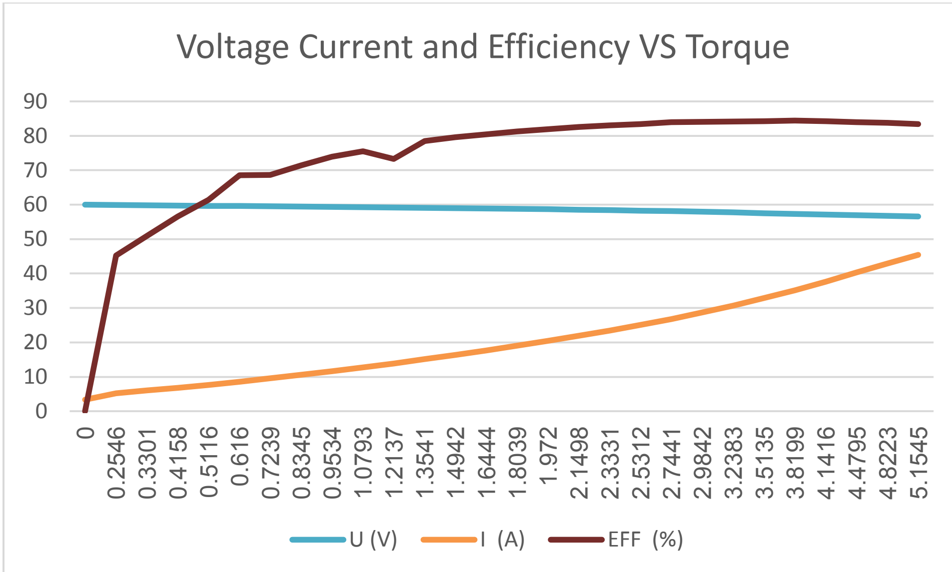


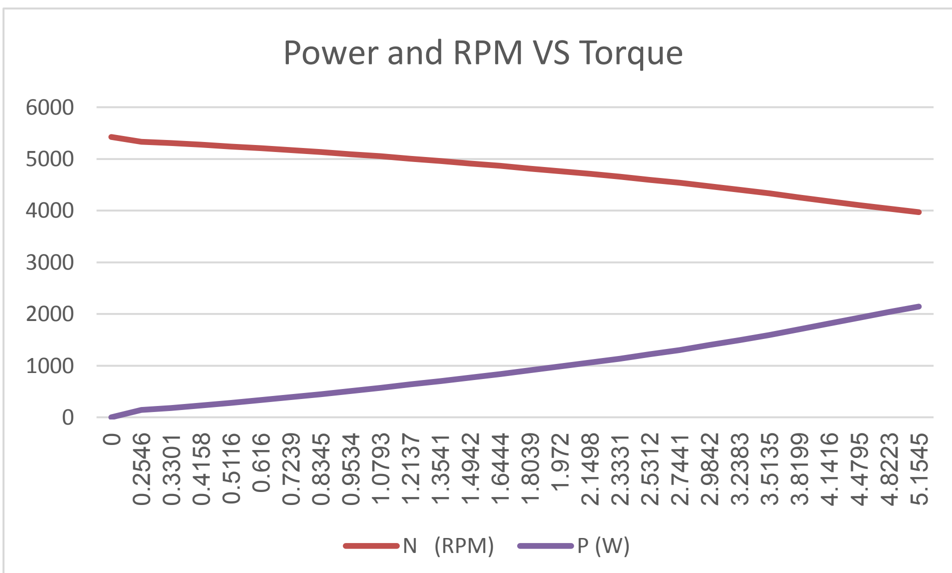
3. Throttle

Figure 12: Throttle

The RPM and torque curve of the motor is as followed:

No	N (RPM)	T (Nm)	P (W)	U (V)	I (A)	Pi (W)	EFF (%)
1	5423.2	0	0	60.027	3.3998	204.08	0
2	5332.7	0.2546	142.19	59.874	5.2527	314.5	45.21
3	5305.1	0.3301	183.35	59.817	6.0172	359.93	50.94
4	5273.4	0.4158	229.59	59.753	6.786	405.49	56.62
5	5240.9	0.5116	280.73	59.684	7.6576	457.04	61.43
6	5206	0.616	335.81	59.607	8.5894	511.98	68.59
7	5169.4	0.7239	391.85	59.527	9.5848	570.55	68.68
8	5132.1	0.8345	448.47	59.449	10.562	627.91	71.42
9	5093.1	0.9534	508.45	59.365	11.588	687.95	73.91
10	5050.5	1.0793	570.81	59.273	12.747	755.53	75.55
11	5005	1.2137	636.15	59.181	13.901	822.69	73.33
12	4959.4	1.3541	703.26	59.079	15.157	895.48	78.53
13	4912.8	1.4942	768.66	58.979	16.37	965.48	79.62
14	4864.8	1.6444	837.65	58.873	17.691	1041.5	80.43
15	4813.2	1.8039	909.19	58.763	19.042	1119	81.25
16	4762.4	1.972	983.37	58.69	20.475	1200.8	81.89
17	4709.7	2.1498	1060.2	58.53	21.943	1284.3	82.55
18	4654.5	2.3331	1137.1	58.407	23.457	1370	83
19	4598.2	2.5312	1218.7	58.273	25.085	1461	83.37
20	4539	2.7441	1304.2	58.136	26.74	1553.6	83.95
21	4473.4	2.9842	1397.9	57.969	28.693	1663.3	84.04
22	4405.9	3.2383	1494	57.792	30.708	1774.7	84.18
23	4333.5	3.5135	1594	57.521	32.898	1892.3	84.25
24	4254.4	3.8199	1701.7	57.325	35.166	2015.9	84.42
25	4179.5	4.1416	1812.6	57.121	37.673	2151.9	84.23
26	4104.9	4.4795	1925.4	56.91	40.281	2292.4	83.99
27	4038.8	4.8223	2039.4	56.759	42.895	2434.6	83.76
28	3967	5.1545	2141.2	56.578	45.396	2568.4	83.37





From the data sheet, it is concluded that the maximum RPM Attainable by the selected motor is 5423 RPM. The torque parameters of the motor need auxiliary enhancement.

Another noteworthy observation is the efficiency column. Greater the efficiency, lower the strain on the batteries and greater the battery life. It was observed that in the RPM range of 4000-5000 Rpm, the efficiency is maximum at about 80%. Hence, maintaining RPM to be around 4000 at all times can result in improved efficiency and battery life.

4. Battery

To power the motor, a battery pack had to be designed. Conventionally, Electric Vehicles employ one of the following:

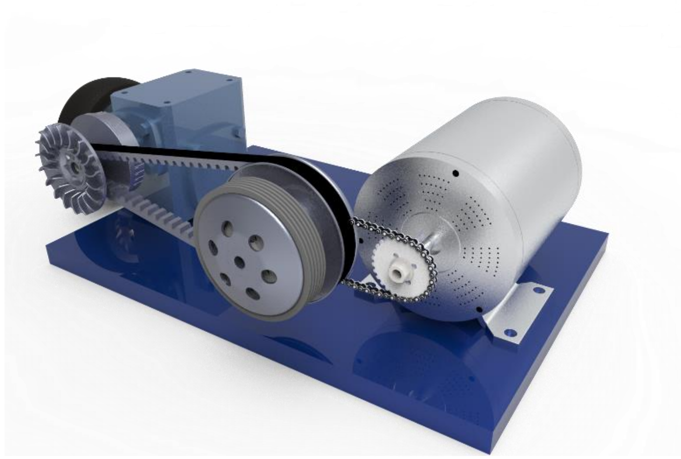
1. Sealed Lead Acid Batteries (SLA)
2. Nickel Cadmium (NiCad)
3. Nickel Metal Hydride (NiMH)
4. Lithium ion polymer (LiPo)

All these options have remarkable power density and drainage capabilities, thereby increasing the distance covered in a single charge. There compactness makes them ideal for scooters and other vehicles.

However, they are incredibly expensive and given the financial restraints we found ourselves in, we had no choice but to opt for the less expensive, conventional Lead Acid Batteries.

The rationale behind this decision is one of necessity. The goal in Electric Vehicle Research is to compete with and surpass Internal Combustion Engine (ICE) vehicles to make EVs a more lucrative alternative. Currently, there are two major domains in improving mileage (Distance covered in a single charge). These are:

1. Improving battery performance
2. Improving transmission



We as a team aimed to focus on improved transmission enhance battery life. Hence, we implemented the less expensive lead acid batteries in our powertrain. The goal is to optimize the transmission as much as possible to get optimum battery power supply and therefore, mileage.

Our final finished prototype looked almost like this high definition render of our CAD. After the assembly was done, the next challenge was to make this assembly compatible with the dynamometer available to us. The dynamometer would test all the performance characteristics, providing us thorough data about the performance of our design.

Continuously Variable Transmission (CVT) Coupling

At the core of our aim to improve mileage by transmission is the CVT. Maximum efficiency of the CVT is desired which in turn delivers optimum battery performance and

Figure 13: High Definition CAD Render

hence, better mileage.

The last challenge that remained before testing our prototype was to find a way to drive the shaft of the dynamometer (the testing machine) with that of the CVT's. The shaft of the CVT was coupled with a head-on chain coupling. A sprocket and spline were specifically designed for this purpose. This sprocket-spline pair encapsulated the shaft of the CVT and established a chain driven mechanism with the dynamometer. The testing of the CVT is explained in the next section.

Assembly Testing

The powertrain assembly was then tested by mounting it on a dynamometer. A base was designed with the specific goal of coupling the powertrain with the dynamometer. After substantial testing, power and torque curves were obtained. Furthermore, the amount of current drawn at specific loads was also noted. These observations are as followed:

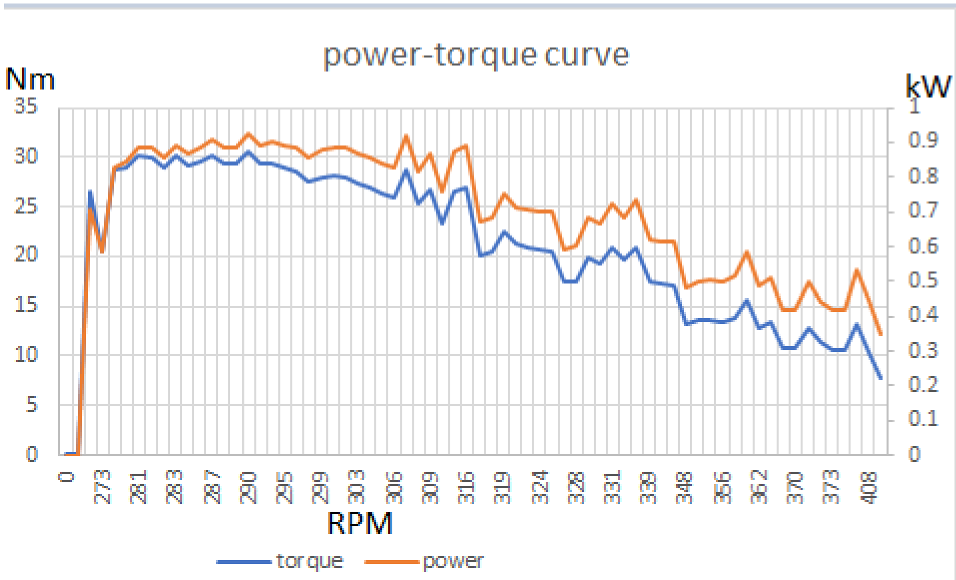


Figure 14: Power-Torque Curves

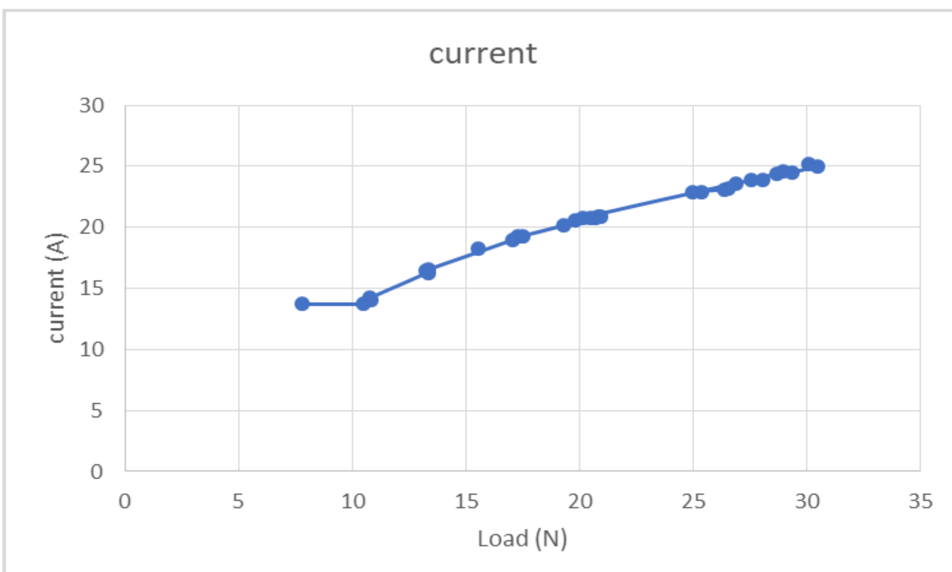


Figure 15: Current Vs Load

CHAPTER 6: CONCLUSION AND RECOMMENDATION

This report documents our final year project based on the ‘design and development of an electric vehicle powertrain’. The model that we kept forward all the way for comparison purposes was an All-Terrain Vehicle (ATV). From the previous section, our motor’s power rating came out to be 2000W with its maximum torque being 4 Nm. This torque would be increased by means of gears to generate the final output torque of approx. 120 Nm.

a. Proof An output torque of 30.9 Nm was achieved on dynamo testing. Employing a gear ratio of 4 for the final gear reduction (differential) can increase the torque to 120 Nm. This shall allow the vehicle to achieve the required gradient.

Achieving our objectives, from complete literature review to feasibility analysis to prototyping a working model of our design, the following conclusions and results were deduced:

1. The peak output torque measured on our prototype is 30.09 Nm.
2. The rotational speed measured at this output torque is 283 rpm.
3. Gear Ratio of the CVT varies up to 6.35.
4. On flat roads, this is equivalent to attaining a speed of 50 kilometers per hour (km/h).
   a. Proof: Force = $\frac{Torque\ at\ tire}{radius\ of\ tire} = f_r.W + \frac{1}{2}\rho.A_f.C_d.v^2$

Torque=30.09 Nm
Tire radius = 0.254 m
Plugging in values in the above equation and solving for velocity, we get v=50 km/hr

5. The vehicle can translate at 30 km/h at a 10% road gradient.

Our work included and focused on the process, one can adopt, to design an electric vehicle which is expected to achieve the same parameters as that of an already present ICE vehicle which, in our case was an ATV. We can apply similar technique and calculation methods to design a more powerful EV. This would obviously demand a higher level of design assumptions and the final design may get more complex, but the basics remain the same as well as the design process.

The design we presented in this report was to the best of the resources available at the time. We believe that the situation can improve if this project is taken as a guidance to understand the thorough design process. Better efficiencies may be achieved using better resources at hand. As the technology advances, better versions of the latest devices come into existence and we hope the same for our very own design as well.

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