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Electric Vehicle Powertrain Sizing

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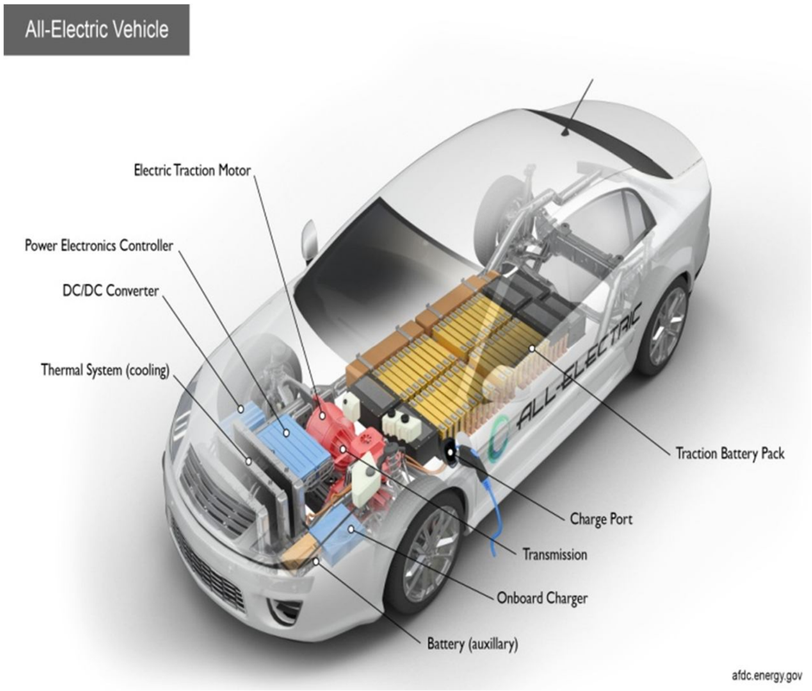
Abstract: Climate change is real! In the recent years the global average temperatures have been increasing steadily due to global warming. One of the main reasons for global warming are the expulsion of gases from vehicles, another aspect is that we are running out of fossil fuels. One way which is mutually going to help in both aspects replacing petroleum run vehicles by power train Electric vehicles. Power train electric vehicle is formed by three components - Engine , Transmission, and Drive train, these are the components which gets engines power to the wheels, and then down to ground. The components of power train converts the stored energy into kinetic energy by utilising various power sources and non wheel based vehicles for propulsion purpose. This paper proposes Electric power train designed for Electric bike. These are light weight and efficient vehicles which require less maintenance and also eco-friendly.

Keywords: Powertrain size, Electric bike, well of wheel analysis.

I. INTRODUCTION

Energy crisis is one of the major concerns in todays world due to fast depleting resources of petrol, diesel and natural gas. In combination with this, environmental decay is an additional factor which is contributing to the depletion of resources which is an alarming notification. All this concerns point out to the requirement of an alternative to the fossil fuels especially in the automobile sector. In such a scenario, the Electric vehicles arrived as potential alternatives to the conventional IC engines. This paper discusses the power train in Electric vehicles, where power train is basically used to produce power required to move vehicle, and deliver it to the wheels. Its main components includes Engine, Driveshaft, and Transmission. Well to wheel analysis is important to get most use of future fuel and power train options. We use Well to Wheel analysis which is important to access the impact of future fuel and power train options Both fuel production pathway and power train efficiency are key to GHG emission and energy use.

II. ELECTRIC VEHICLE SUBSYSTEM



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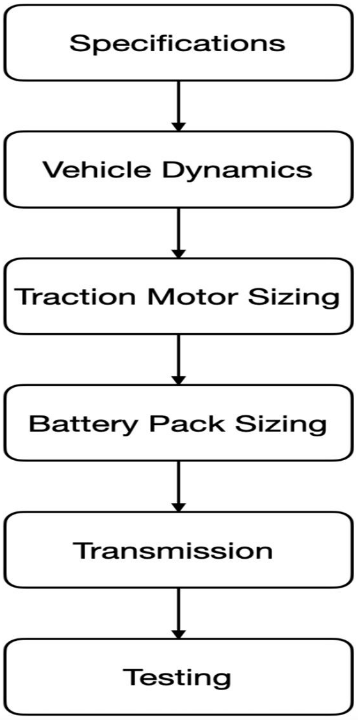
The electric vehicle system consist of various components that work together in order to move the vehicle forward. These components are divided into various subsystems. Further in order to design an electric vehicle effectively it is necessary to have an understanding of various subsystems involved in it. The figure1 shows an overview of various subsystems involved in an electric vehicle.

1) *Traction Motor:* The Traction Motor takes the electrical energy supplied by the Battery at the input and converts it into a mechanical energy at the output which makes the vehicle move. The traction motor plays the role of an engine. It makes the automobile move.
2) *Power Electronics Converter:* The primary task of power electronics is to process and control the flow of electric energy by supplying voltages and currents in a form that is optimally suited for user loads. Modern power electronic converters are involved in a very broad spectrum of applications like switched-mode power supplies, active power filters, electrical-machine-motion-control, renewable energy conversion systems distributed power generation, flexible AC transmission systems, and vehicular technology, etc.
3) *Traction Battery Pack:* lead acid traction battery are used as power sources for electric propulsion in applications which include road vehicles, locomotives, industrial forklift trucks and mechanical handling equipment(MHE).
4) *Transmission:* This subsystem helps in transferring the generated mechanical power at the shaft of the motor to drive the mechanical Load at the wheel axis. Provide means of connection and disconnection of engine with rest of power train without shock and smoothly. Provide a varied leverage between the engine and the drive wheels. Provide means to transfer power in opposite direction and it Enable power transmission at varied angles and varied lengths.
5) *Charger:* This is the part that allows the Electric Bike to be able to be recharged and used again. It’s usually an adapter that is connected to AC supply directly(230v) and this converts the AC into DC (12V) which then recharged the battery.
6) *DC/DC Converter:* This block is used to step down the higher voltage available from the Traction battery pack to a lower voltage(usually 12V) since various auxiliary applications work have this voltage. Auxiliary applications include Headlights, Tail-lights, Horn, Digital Odometer and various other on-board electronics for UI/UX. Usually a DC-DC converter such as buck converter is used for this purpose.

III. DESIGN PHASE

The design phase of an electric vehicle involves various stages which are summarised in the flowchart given below.



A. Requirements/Specifications

The first stage of the design phase starts with listing down the various parameters for the vehicle. These parameters are decided based on the performance that the vehicle expected to provide. The various parameters that are to be decided in this phase involves:

1) *Max. Vehicle Speed.* **-** The maximum speed the vehicle is expected to achieve.
2) *Max. Acceleration* **-** The acceleration the vehicle can provide. For example : 0kmph to 50kmph in 10 seconds.
3) *Mass of the Vehicle* **-** The Mass of the vehicle including the chassis, all the components and the passengers.
4) *Grade Angle* **-** The maximum inclination the vehicle expected to climb.
5) *Range* **-** The maximum distance the vehicle is expected to run on a single charge.

These requirements are decided keeping in mind the end performance the vehicle must give, post-production.

B. Vehicle Dynamics

For vehicles such as cars, vehicle dynamics is the study of how the vehicle will react to driver inputs on a given solid surface. It deals with the analysis of various forces acting on the vehicle and how the affect the motion of the vehicle. This involves the application of classical mechanics to the analysis of forces on the vehicle.

In order to design the vehicle accurately, the various forces acting on it and the torque required to move it should be known. The required torque for moving the vehicle forward depends on various forces that are acting on it like force needed to provide acceleration ,rolling resistance, aerodynamic resistance, grading resistance friction et cetera.

The required traction force on the tire of the vehicle is Ft . The force Ft induced on the edge of the vehicle tires is to move it itself. The force traction required for the vehicle on the ground level is shown by Eq. (1):

Ft = Fa + Fr.

where, the force needed for linear acceleration of the vehicle is Fa. The required force to overcome the resistance to vehicle traffic is Fr.

The force needed for linear acceleration i.e. Fa can be written as :

Fa = M*a.

where, M is the mass of the vehicle and ‘a’ is the acceleration as per the specification in the first phase.The force required to overcome the resistance to vehicle that is Fr depends upon the various resistive forces acting on the body. Some of the significant resistive forces are :

1) *Rolling Resistance:* A tire subjected to a load will be deformed and flattened until the contact area with the ground will get a force equal to the load on the same wheel. When the tire rolls, the resulting force at contact is not centred but placed at a distance. This results in a torque which is in the opposite direction of the tractive torque and tends to slow down the rotation. Also, because of the elastomeric property of materials used in the tyre, a portion of energy is lost because of the deformation and reformation of tyre which must be provided by the power source itself. The resistive force due to rolling resistance can be calculated as :

Froll = GVW*CRR

where, GVW is gross vehicle weight(Total vehicle weight) and CRR is coefficient of rolling resistance(a number that is the property of surface).

2) *Aerodynamic Resistance:* Aerodynamic resistance is the force that opposite vehicles motion through the air. As the vehicle starts starts moving, there is a relative motion between the vehicle and the surrounding layers of air. As a result there is a presence of fluid resistance. This accounts to aerodynamic resistance. The two types of aerodynamic drag i.e. pressure drag and skin friction drag account for the total aerodynamic resistance for the vehicle. The total aerodynamic resistance can be calculated as :

Faero = 1/2*CD*A*ρ*V2

where, CD is coefficient of drag (a number that shows how streamlined a shape is, Lower CD numbers show that there is less drag) , A is the frontal area of the vehicle, p is the density of air and v is the velocity of vehicle.

3) Grade Resistance: When the road is inclined at an angle ‘x’ then the gravitational force acting on the vehicle can be resolved into two components i.e. parallel and perpendicular component. When the vehicle goes uphill, the parallel component acts in the direction opposite to that of the motion of vehicle. This is termed as Grade resistance. The Grade resistance can be calculated as :

Fgrad = M*g*sin(x)

where, M is the mass of the vehicle, g is acceleration due to gravity, x angle of inclination. Thus, the total tractive force required can be calculated as :
Ft = Fa + Froll + Faero + Fgrad.
The total tractive torque required can be calculated as:
Tt = Ft * (d1/2).
where Ft is the tractive force and D1 is the diameter of the Tyre.
In order to calculate the Torque that is to be provided by the Motor(Tm), we have to take into consideration the Gear ratio.Let the Gear ratio used in the transmission be of the ratio :
Gear ratio = N2/N1.
Where, Now we can calculate the Torque to be provided by motor(Tm) as:
Tm = Tt / (N2/N1).

C. *Traction Motor / Controller Sizing*

An Electric motor is a device which converts electrical energy into mechanical energy. The Traction Motor takes the electrical energy supplied by the Battery at the input and converts it into a mechanical energy at the output which makes the vehicle move. The traction motor plays the role of an engine. It makes the automobile move. The classification of various types of traction motors is shown in figure below.

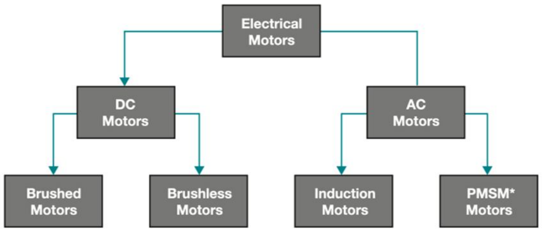


Figure 2 : Classification of Motors figure

The Traction motor is responsible for providing the amount of tractive torque and tractive force required by the vehicle to perform as per the design specifications. Hence the choice of tractive motor for a particular vehicle is done by taking into consideration of the calculated torque, the required rpm and the power requirements. The comparative analysis is given below.

1) *Brushed DC Motor*
a) *Voltage levels :* <100V
b) *Power levels :* <100W
- Applications : Toys, coffee machine, gate openers etc.
- Advantages : Easy to control, low cost.
- Disadvantages : Brushes wear out, Inefficient.

2) *Brushless DC Motor*
a) *Voltage Level :* <600V
b) *Power Levels:* Upto a few kW
- Applications : Household appliances, pumps etc.
- Advantages : Long life/reliable, high-efficiency.
- Disadvantages : Cost, complicated control circuit.

3) Induction Motor :
a) *Voltage Levels :* >600V
b) *Power Levels :* >750W
- Applications : Industrial and factory automation.
- Advantages : Low-cost, less maintenance and reliability.
- Disadvantages : starting issues, low power factor correction, complicated speed control.

Thus by taking into consideration of the voltage and power levels and also the pros and cons of each type of motor, a suitable type is selected for that particular design of the vehicle. We can relate to the voltage, current and various other parameters of the motor as:

$U = LdI/dt + IR + Kemf*w$.

where, U is the voltage applied to the motor, I is the current flowing through the motor, w is the angular velocity of the shaft, Kemf is the back emf constant.

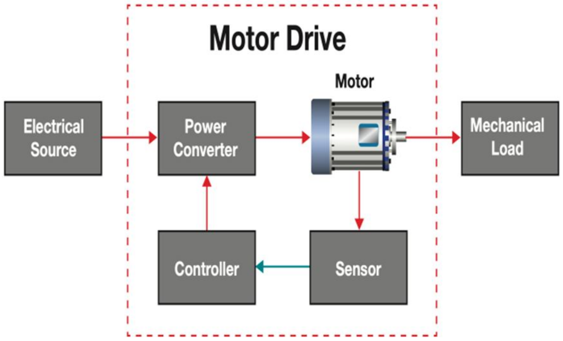


Figure 3 Motor Drive figure

After the choice of Motor, the power electronics required can also be properly chosen. The Power converter topology in the power converter circuit is different for different type of motors. However, they all involve a closed loop control system along with Motor drivers at the end of its stage. The voltage and Power requirements should be taken into consideration while deciding the threshold for these Power electronics circuits.

D. Traction Battery Sizing

The traction Battery pack is one of the most important components of an electric vehicle as it is the source of energy for the vehicle to operate. A battery consist of one or more electrical electrochemical cells which are converting chemical energy into electrical energy and electrical energy into chemical energy. In order to design a battery pack there are four core input parameters that are to be considered. Each of these parameters with their design constraints is described in this section.

1) *Chemistry of Cell:* A battery which consists of one or more electrochemical cells is made up of various components like anode cathode separators electrolytes et cetera. The type of elements contained within the battery and the chemical reactions during discharging and charging events define the chemistry of a battery. There are several type of cell chemistries that are available in the market. Some of the major cell chemistries are Lead-acid, NiCd, NiMH, NaNiCl, Li-polymer, Li-ion etc. The choice for the type of cell chemistry depends upon factors like- specific energy(Wh/kg) , Energy density(Wh/m3), Specific Power, efficiency, cell longevity , cost and other factors. The Figure below shows the comparison of Specific power and associated Specific energy for varying types of battery chemistry.

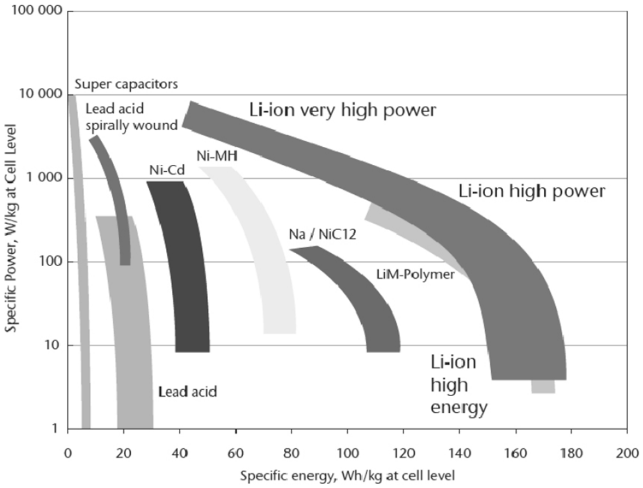
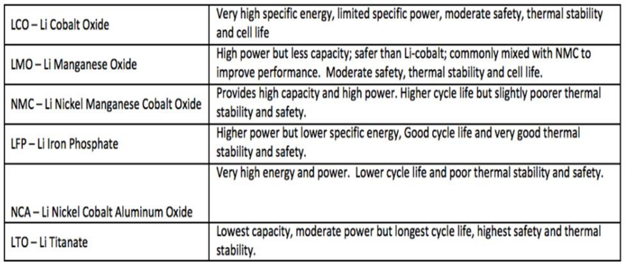


Figure 4 Li-ion comparison diagram

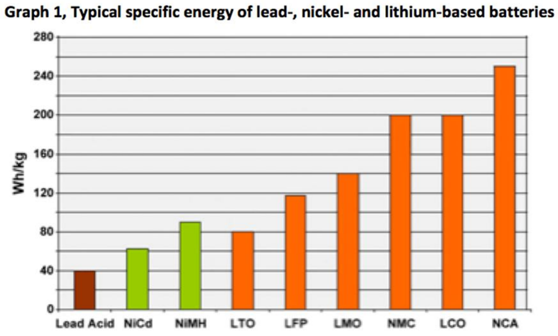
Usually Lead Acid or Li-ion based chemistry are used for Electric vehicle applications. The quest for Higher Specific Power batteries and higher efficiency has lead to the use of Li-ion based chemistry as an obvious choice for Electric vehicles. The Li-ion cells have further variations like LCO, NMC, NCA, LMO LPF etc. The selection of a particular variety of Li-ion cell is again based on design constraints and application specificity.

Table 2 Types of Lithium-ion.



LCO – Li Cobalt Oxide	Very high specific energy, limited specific power, moderate safety, thermal stability and cell life
LMO – Li Manganese Oxide	High power but less capacity; safer than Li-cobalt; commonly mixed with NMC to improve performance. Moderate safety, thermal stability and cell life.
NMC – Li Nickel Manganese Cobalt Oxide	Provides high capacity and high power. Higher cycle life but slightly poorer thermal stability and safety.
LFP – Li Iron Phosphate	Higher power but lower specific energy, Good cycle life and very good thermal stability and safety.
NCA – Li Nickel Cobalt Aluminum Oxide	Very high energy and power. Lower cycle life and poor thermal stability and safety.
LTO – Li Titanate	Lowest capacity, moderate power but longest cycle life, highest safety and thermal stability.

Figure 5 Li-ion types figure



2) *Pack Voltage and Current:* After deciding the type of cell chemistry, the next parameters to be decided are the battery pack voltage and the battery pack current. Both these parameters are dependent upon the requirement of the motor drive unit. The battery pack voltage should be well in the operating region of the motor Drive unit. Further the amount of current that the motor drive unit draws from the battery pack should be within its safe operating conditions. The current and the voltage drawn by the motor drive unit from the battery pack should be such that there won't be any abusive usage of the battery pack and it remains well within its safe operating conditions. The voltage level of the battery determines the maximum electrical power which can be delivered continuously. Power P is the product between voltage U and current I:

P=U*I

The higher the current, the bigger the diameter of the high voltage wires and the higher the thermal losses. For this reason, the current should be limited to a maximum and the nominal power obtained by having a higher voltage.

3) *Average Energy Consumption:* The average energy consumption of the vehicle for propulsion(Ep) can be calculated by considering the drive cycle of vehicle.On top of the energy needed for propulsion, the high voltage battery must supply the energy for the vehicle’s auxiliary devices (Eaux), like: 12 V electrical system, heating, cooling, etc. Also, we have to consider the efficiency of the powertrain ηp [-] during the conversion from electrical energy to mechanical energy.

Eavg = (Ep + Eaux)(2- np).

4) *Battery Pack Capacity:* The Battery Pack capacity which is measured in Ah indicates the amount of charge the Battery pack can store. The capacity of the battery pack decides the range of the Electric vehicle. The greater the Pack capacity, farther the vehicle can go in a single charge. The calculation for the Range and Battery pack capacity should also take into consideration of the performance of the vehicle at that instant of time and the drive cycle of the vehicle. Taking these factors into consideration, the Battery Pack capacity is decided.

5) *Battery Pack Architecture:* Individual battery cells may be grouped in parallel and / or series as modules. Further, battery modules can be connected in parallel and / or series to create a Battery Pack. Depending on the battery parameters, there may be several levels of modularity. The total battery pack voltage is determined by the number of cells in series. The total voltage of ’n’cells connected in series will be the sum of their individual voltage.

Vpack = V1+V2+V3+……Vn.

In order to increase the current capability and the battery capacity, more cells have to be connected in parallel. The total capacity of a battery pack with ’n’ cells connected in parallel will be the sum of their individual capacities.

Cpack = C1+C2+C3+………Cn.

Hence based on the requirement of Battery pack voltage and capacity, the Battery pack architecture is decided. Some examples of Pack architecture include 13s12p(12 groups in parallel with each group having 13 cells in series), 2s3p etc. After designing the battery pack the appropriate Battery Management system(BMS) and charging equipment must be used. The BMS plays an important role in the safety of operator, protecting the battery pack, SOC estimation, SOH estimation etc. The power rating of BMS and charging equipment should match with that of the Drive circuit and Traction battery pack.

E. Transmission

This subsystem helps in transferring the generated mechanical power at the shaft of the motor to drive the mechanical Load at the wheel axis. Some of the major types include :

1) *Direct Transmission:* The load and the motor are directly connected.
2) *Belt Driven:* The Motor is connected to the load with the help of Timing belts or V-type belts.
3) *Chain Driven:* The Motor and the wheel are connected with the help of chain and sprocket.

Chain Driven is the most commonly used type. There will be usage of gears in the chain driven and Belt Driven case to match the Torque, rpm provided by motor to the required Torque, amp to move the vehicle. Usually, the number of teeth(or diameter) of the gears used at both end will be different. The gear used at the motor shaft end is called ‘Driving gear’ and the gear used at the wheel end is called ‘Driven gear’. The ratio of these two is called ‘Gear Ratio(GR)’.

GR = Output/Input = Driven/Driver.

GR = N2/N1

Where, N2 is number of teeth in output gear and N1 is the number of teeth in input gear.

GR = N2/N1 = Tm/Tw

Where, Tm is the motor torque and Tw is the wheel torque.

GR = N2/N1 = Ww/Wm

Where, Ww is the wheel rpm and Wm is the motor rpm.

IV. PRACTICAL APPLICATION TO AN ELECTRIC TWO-WHEELER

This section describes the application of the above given design steps to the design of an electric two wheeler. Usually the powertrain sizing of an electric vehicle is done after considering the drive cycle of the vehicle like UDDS, Indian driving cycle or any other standard drive cycles. Further the design steps are implemented by modelling the entire electric vehicle in mathematical environments such as Matlab, Scilab et cetera. This section describes the calculations involved for one particular point in a drive cycle. At that point the vehicle is assumed to have attend the maximum speed and is travelling on a flat Road.

A. Specifications/Requirements

The first step is to start with a set of basic requirements/specifications which are decided based upon the end product in mind. The requirements for the electric two wheeler to be designed are as follows:

Mass of the vehicle with passengers = 150kg
Acceleration due to gravity = 9.81 ms-2
Top speed = 40kmph. 0 kmph to 40 kmph in 10 seconds.
Acceleration = 0.12 ms-2 [almost (1/10)th of uniform acceleration].
Wheel size = 24 inches [both rear and front wheel].
Range = 40 kms.

B. Vehicle Dynamics

The Next step is to calculate all the forces that are acting on the vehicle so that the tractive force required to move the vehicle can be obtained. In order to calculate the values of rolling resistance and aerodynamic force we need to know the values of certain parameters like CRR, coefficient of aerodynamic drag, frontal area of vehicle et cetera. These values can be obtained by conducting tests like cost down tests(for CRR), wind tunnel test or by performing CFD analysis in the simulation software environments like ANSYS etc. The values obtained are as follows:

Coefficient of aerodynamic drag = 0.22.
CRR = 0.015 [concrete road].
Frontal area = 0.875 m2.

Further, the resistive forces acting on the vehicle are calculated by using the above given equations as follows:

Froll = [150*9.8]*0.015 = 22.05N.
Faero = 1/2*1.225*0.22*[11.11]^2 =14.55N. [Density of air = 1.225kg/m3]
Fgrad = [150*9.8]*sin0 = 0N.

The force needed for acceleration is calculated as:

Facc = [150*0.12] = 18N.

The total tractive force is thus given by:

Ft = Facc + Froll + Faero + Fgrad = 54.6N.

Hence the total tractive torque required is:

Tw = Ft * (d/2) = 54.6*0.3048 = 16.64Nm.

Similarly the wheel rpm can be calculated by knowing the velocity of the vehicle as follows:

Wwheel = velocity/radius = 40*(5/18)/0.3048 = 36.45 rad sec-1 = 348.25 rpm.

Before proceeding to the next step, the gear ratio need to be calculated. For this particular vehicle, let the front gear be of 13 teeth(N1=13) and rear gear be of 42 teeth(N2=42). Hence, Gear ratio = N2/N1 = 42/13.

C. Traction Motor / Controller Sizing

This step involves calculating the motor specifications and the type of motor correspondingly. Before deciding the type of motor, the specifications for the motor need to be calculated from the Tractive force and Tractive torque obtained in the previous stage.

Motor Torque (Tmotor) =Tmotor = Tw/ Gear ratio = 16.64/[42/13] = 5.15 Nm.
Motor rpm (Wmotor) = Wmotor = Wwheel * Gear ratio = 1125.12 rpm.

Motor Power(Pmotor) = n*Pmech + losses + grading factor= 0.85 * 600W+100W = 805 W. Based on the available options for Motors in the market and by considering the above parameters, an appropriate type of electric motor can be chosen. Motor Type : Brushless DC Motor.

Motor Voltage : 48 V.
Motor rating (Power rating) : 1000W.
Motor Current : 40A.
Rated Torque : 4.5 Nm.
Star connected windings for good starting torque.
Commutation angle : 120.
Efficiency : >87% on full load and full rpm.
Controller type : Sensored BLDC Motor controller.
Position sensors : Hall effect sensors.
Number of mosfets : 24 mosfets.

D. Traction Battery Sizing

The Traction Battery pack is designed considering the Voltage, Power requirements of the Motor drive unit and the range of Electric vehicle. The specifications are as follows:

Cell chemistry = Li-ion cell of LPF type.[LPF considering the good efficiency and low cost].
Battery Pack voltage = 48.1V
Continuous discharging current = 50A.
Battery Pack architecture = 13s 13p combination.

Battery Pack capacity = 30Ah
A suitable BMS board should be used along with the Battery Pack with suitable ratings.

E. Transmission

A chain driven system can be used for this vehicle. At the motor side, the front sprocket used should be of 13 teeth. At the wheel side, the rear sprocket used should be of 42 teeth.

V. FUTURE SCOPE

A. Battery Management system(BMS) can be improved to provide SOC, SOH and other secondary functions.
B. BLDC motors can be replaced by more powerful and efficient PMSM Motors.
C. Further, upon using PMSM motors, Vector based motor controllers can be used which provide great accuracy.
D. Regenerative breaking system can be implemented which uses the energy that would be wasted while breaking to charge back the battery pack in the EV.
E. Liquid cooling systems can be used to develop better thermal systems.

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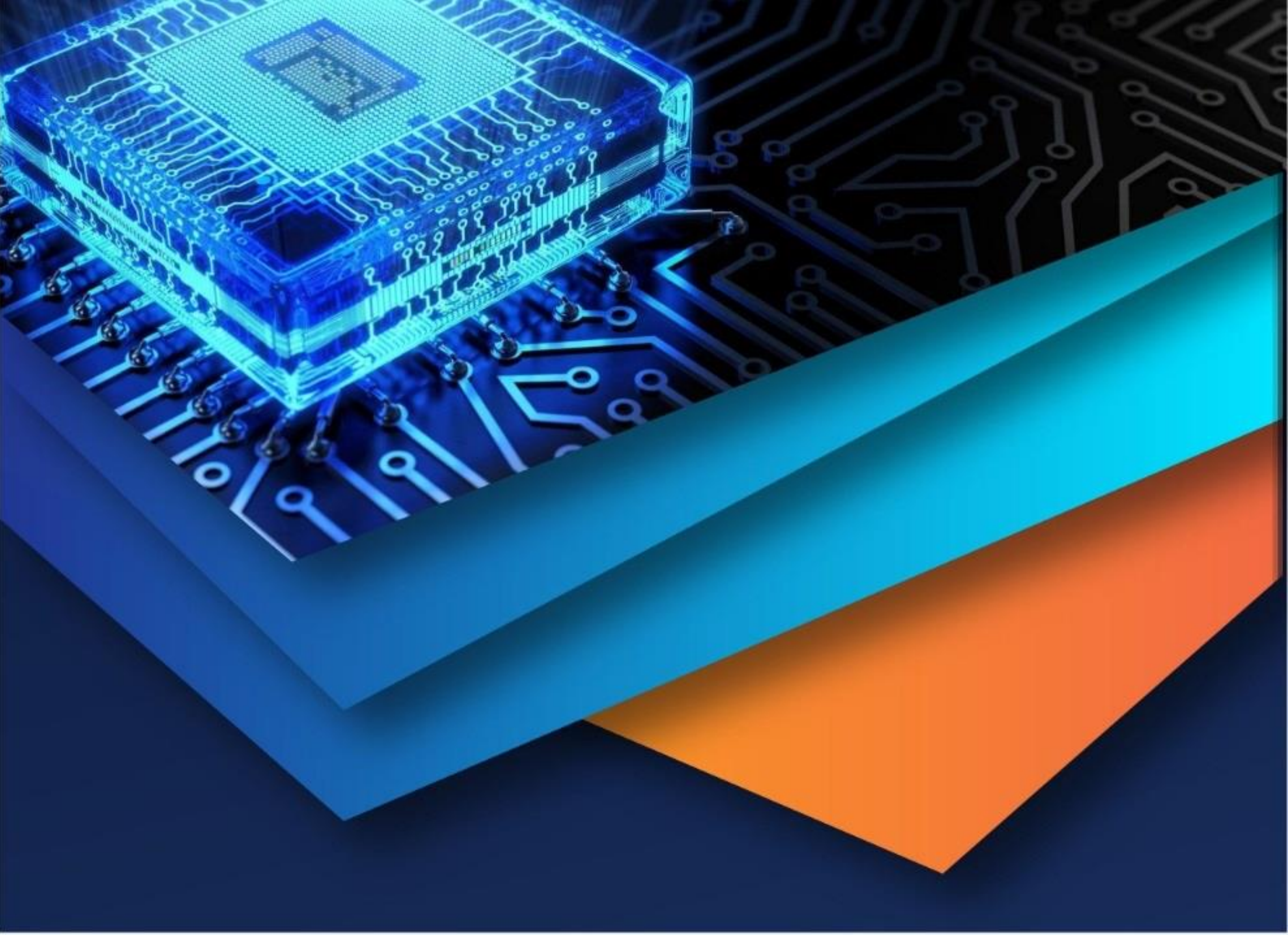

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