Design of Electric Light Utility Vehicle

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Abstract - *This paper addresses the technique, general design, analysis, performance characteristics of the designed Electric Light Utility Vehicle. The EV is a two-seater and has a 540 L load bin. The objective was to keep the vehicle lightweight, easy to manufacture, a model of innovation having good performance in varied terrain. The vehicle primarily runs on batteries and is supported by solar panels and regenerative braking. The objective of the design process is to create a solid, industry-standard design. The vehicle's specifications are detailed in calculations for the drivetrain, steering, batteries, and solar panels. The vehicle has been designed to carry loads in excess of 250 Kg. Power characteristics are also simulated to ascertain working conditions for battery discharge and powertrain response.*

Key Words: **Electric Vehicle, LiFePO4 Batteries, Utility Truck, Vehicle Design, Solar, Electric Transmission, Calculations.**

1. INTRODUCTION

This design iteration helps us work towards our Indian dream of an Atmanirbhar Bharat by developing indigenous Electric Vehicle Technology. The design is an electric utility vehicle with a two-person seating capacity that runs primarily on batteries and is supported by solar panels. The goal of the design phase has been to design an industry-standard design for a light electric vehicle that can perform admirably in a variety of environments. Initially, the task was to research literature and resources to scour for the latest technology and developments in the exponentially growing EV Industry. To build the most competitive vehicle, all of the preset limitations, cost concerns, as well as technical elements were borne in mind when designing.

1.1 RESEARCH AND CONCEPTUAL DESIGN

Over the last thirty years, the reduction of vehicle weight has been an important factor for manufacturers. This is due to two overbearing factors i.e. increase in prices of fuels due to scarcity of crude oil and growing awareness for environmental conservation and reduction of the global carbon footprint. It is a simple formula: if the weight of the vehicle is decreased, the energy consumption by the motor is also decreased. A lighter vehicle's emissions and fuel consumption will be lower than a heavier vehicle due to the reduced energy requirements. Alternative propulsion methods have been developed as a result of the automotive industry's efforts to reduce emissions and fuel consumption, and in particular Electric mobility. Extensive R&D, new types of batteries now have a higher power density than before, permitting electric cars to travel farther than before. This coupled with the fact that Electric vehicles have much fewer moving parts than typical Internal combustion Engine vehicles and thus require less service and maintenance.

To begin with, EVs are non-polluting, even if their power source, coal, is likely to be polluting. EVs are ecologically beneficial since they don't emit exhaust gases, which are harmful to the environment. Electric motors convert about 70 percent of the chemical energy from batteries to power the vehicle's traction wheels, while internal combustion engines (ICEs) only convert about 20 percent of the gas' energy. Electric motors are indeed silent and additionally reduce noise pollution.

Through multiple iterations, and trade studies, a concept vehicle is developed and it is thoroughly analysed to eliminate design flaws.

2. VEHICLE SPECIFICATIONS:

Powered by lithium-ion batteries and solar energy, this electric utility vehicle is a zero emission vehicle for metropolitan areas. Fuel consumption management, safety, new materials and economic safety are all addressed by this vehicle, which is utilized as an innovation platform for the development and testing of new technology in the EV spectrum. After multiple iterations, the vehicle specifications were set as follows:

Table-1: Vehicle Specifications

Vehicle Type	Light Utility vehicle	**Occupants**	2
Max Speed	25km/hr	**Bin carrying capacity**	0.54m^3 / 540lit

Dimensions	2963x1681x1805 mm	**Solar panel specification**	300W, 168.4cm x 92.2cm
WheelBase	2178 mm	**Aerodynamic Drag Coefficient**	0.84
Track width	1465 mm	**Electric motor specifications**	3000Rpm, 6.36Nm
Kerb Weight	258.43kg	**Charging Time**	10hrs
Ground clearance	151 mm	**Range per charge**	30 Km

3. DETAILED DESIGN DEVELOPMENT:

A design is a plan for the construction of an object or system for the implementation of a process, the result of which forms a prototype, product, or process. The Vehicle is designed keeping in mind the robustness of the design. Major emphasis is laid on the following points throughout the development phase:

1. Safety and ergonomics
2. Standardization as per industry
3. Maneuverability
4. Safe engineering practices
5. High-quality cost ratio
6. Power and performance
7. Stability and long product life

Features:
Taking references to Golf Cart models Such as the Polaris Ranger EV and some other International designs, a conceptual sketch was drawn finalizing the design of the Vehicle by taking into consideration the set parameters and the ease of manufacturing.

Frontal Section: The bonnet and the front bumper is of the length 727mm which houses the front tyres and the McPherson strut suspension. Under the hood, the main connections to the steering system, electronics, headlights, and the vehicle's central control unit are placed. The hood is easily openable, facilitating easy access to the inside.

Cabin: The dashboard acts as the main interface between the passengers and the vehicle and it can be made of Polypropylene and developed to house modern features like a 7in touchscreen with Bluetooth and Wifi. It is easily programmable to the user's needs and gives details about the vehicle such as the battery charge percentage, vehicle speed, distance traveled, distance to next charge, infotainment, and many more. The steering is a simple rack and pinion arrangement adopted from the TATA Nano.

The total area of the cabin is 0.9m^2. The cabin floor can be made of chequered Aluminium of 4 mm thickness, giving excellent loading strength.

Load Bin: The load bin is placed just behind the cabin and is made of Aluminium sheets of thickness 5 mm. Aluminum extruded rods and angles are used for support and attachment. The tailgate is joined using Latches to the base of the bin and for fastening.

The bin rests on the chassis with the help of fixtures as shown in the subsequent figures.

The total volume of the bin is 540 Litres and can be used to carry all types of loads up to 250 Kg.

Additional features: The vehicle can also have a toolbox situated below the seats to store tools and accessories. Handlebars are provided for easy access to the cabin.

The entire Design flow of the vehicle is also divided into:

- Chassis
- Transmission
- Brake
- Steering
- Suspension
- Fixtures
- Motor
- Battery
- Solar panel

3.1 CHASSIS:

A chassis serves as a skeleton that structurally supports an automobile in its construction and function. In addition, it is responsible for connecting all the important components, including suspension, brakes, and drive train with the highest degree of safety. A factor of safety of 3 was considered to safeguard the vehicle from adverse deformation or shearing. It was also important to ensure the safety of the occupants, provide fixtures for mounting of suspension and drivetrain, reduce noise, vibration and harshness. Keeping the above points in mind, we found that the ladder frame chassis is a perfect fit. All the load members of the chassis were Box Beams made of AISI 4130 Steel. The material was selected after carefully weighing up the cost, material properties, and testing results obtained from various books and resources.

Below is the CAD model that shows the design of the chassis:

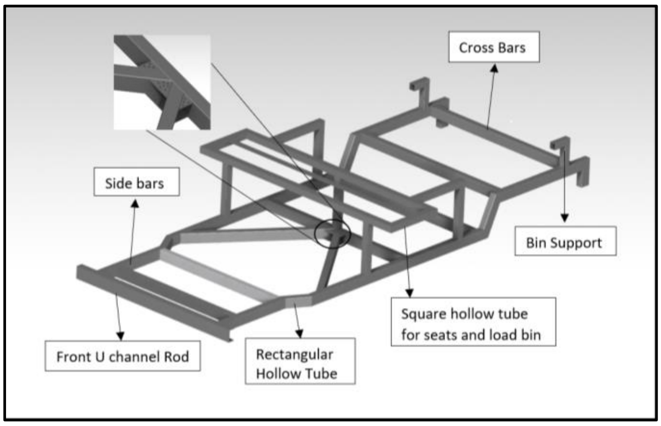

Fig-1: Chassis Members

3.1.1 CHASSIS STRUCTURE AND MATERIAL SELECTION

The chassis can be built using a tubular space frame, consisting of Rectangular tubes for a sturdy construction. The chassis frame has two beams placed longitudinal (long members) and connected with a number of cross members ensuring stability and strength. The ladder frame chassis is very durable and easy to construct. Since the body is simply bolted to the ladder along with everything else, parts and even whole sections can be replaced relatively easily.

The longitudinal beams are Rectangular hollow tubes with the following dimensions 60x40x3.6 mm and the cross members are of dimensions 60x40x2.9 mm.

The frame for the seating arrangement and the loading bin are of square hollow tubes of dimensions 40x40x4 mm, at the front a U-channel of 75x40x5mm is added as a support member which also acts as an air dam.

The Dimensions of the Vehicle chassis are 2887x1100x430mm (LxBxH).

Selecting a Material with the most suitable properties was a challenging task. Properties, costs were mainly considered whilst designing the chassis. Materials of high strength yet lightweight and economical were thoroughly studied and AISI 4130 Alloy Steel was selected. In this alloy, Molybdenum and Chromium act as strengthening agents, which also has a low carbon content; the alloy also has excellent weldability.

The mechanical properties of AISI 4130 are:

Table-2: AISI 4130 Mechanical Properties

Mechanical Properties	Data
Density	7.7 g/cm^3
Poisson's Ratio	0.3
Tensile Yield Strength	435 MPa
Ultimate Tensile strength	560 MPa
Elongations	28.2 mm
Bulk modulus	140GPa
Elastic modulus	210GPa
Shear modulus	80GPa

3.1.2 ANALYSIS OF CHASSIS:

The Vehicle chassis was analysed using ANSYS to determine its structural strength and stability. Setting a cycle size of $10^6$and a total force of 6000 N in negative z-axis, it was established that the maximum deformation is 0.509 mm and Maximum principal stress of 68.66 MPa that is far less then the ultimate yield and tensile strength thus the chassis is safe to carry a load of 600 kg with least deformation and 750 Kg without failure.

The tabulation below signifies the safety of the Vehicle:

Table-3: Stress

	Total Deformation (mm)	Equivalent Stress (MPa)	Max Principal Stress(MPa)	Ultimate yield stress of the material (MPa)	Factor Of Safety
Minimum	0	0	-9.48	460	1.5
Maximum	0.509	63.64	68.66	460	15

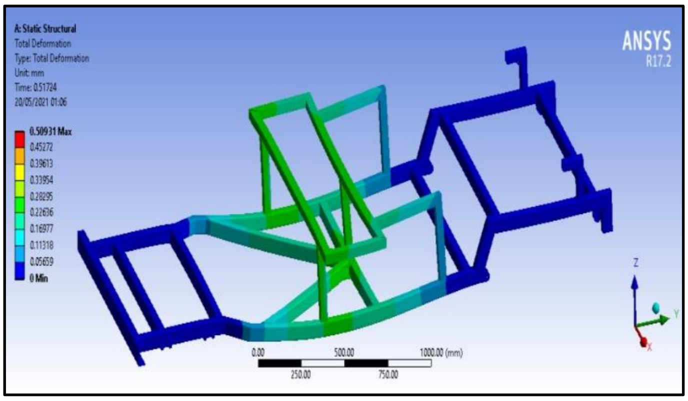

Fig-2: Stress Analysis

3.2 TRANSMISSION:

A transmission or powertrain is a system that transmits power in a controlled manner. Any transmission system typically consists of a gearbox that uses gears and a set of gear trains to provide the necessary speed and torque conversions from a rotating power source (motor) to the traction at the wheels.

The main components of any transmission include the transaxle, motor and motor controller.

In an EV, the need for a separate gearbox is eliminated because of the inherent electric transmission. A motor is used instead of an engine and single-speed reduction Transaxle can also be used. A transaxle is the assembly of a differential gear where one step reduction is coupled with a rear axle and hub, directly mounted onto the chassis of the vehicle.

Through extensive market research, it was established that there are various standard transaxles available for use in EV's with various reduction gear ratios. A transaxle with a reduction ratio of 10.45 was chosen as a basis for our vehicle.

The calculations for vehicle transmission are as follows:

Parameters set:

- ➔ Motor= 2kW, 3000 RPM
- ➔ Transaxle reduction ratio= 10.45
- ➔ Tire= 18 x 8.5 x 8

Top Speed of the vehicle:

Rpm of Motor= 3000

Transaxle reduction= Tr= 10.45

Radius of tire= 0.458m

$$RPM\ of\ Wheel = \frac{RPM\ of\ Motor}{Transaxle\ reduction} \quad \rightarrow(1)$$

Therefore, RPM of motor =

M_{rpm}= 287.08 rpm or 4.78 rps

$$Speed = rps \times Circumference\ of\ tire \quad \rightarrow(2)$$

Therefore, Speed = 24.8 Km/h or 6.9 m/s

Factors affecting the Torque requirement:

When selecting a driving motor, various factors must be considered to establish the torque characteristics required:

- ➔ "Rolling Resistance
- ➔ Grade Resistance
- ➔ Acceleration Force"

Rolling Resistance (RR):

Rolling Resistance can be defined as the opposing force that a vehicle must overcome as a consequence of the rolling motion between the wheels and the ground. The rolling resistance depends on the coefficient of rolling friction which varies depending upon the tyres and the surface roughness of the contact area.

$$RR = W_g \times C_{rr} \quad \rightarrow(3)$$

where,

W_g= gross weight

C_{rr}= Coefficient of Rolling Resistance

Considering,

W_g= 525 Kg

C_{rr}= 0.06

Therefore,

$$RR = 309\ N$$

Grade Resistance (GR):

Grade resistance is a form of gravitational force where the force tends to pull back the vehicle when it is climbing an inclined surface.

$$GR = W_g \times sin\theta \quad \rightarrow(4)$$

Where,

θ =Grade or inclination angle

Considering, $\theta = 10\%$

$$GR = 895\ N$$

Acceleration Force (Fa):

Acceleration force is the force that helps the vehicle reach a particular speed from its position of rest within a defined frame of time. The motor torque has a direct relationship with this force.

$$F_a = m \times a$$

where. m= 53.5 N

$a = 0.12\ m/s^2$ (from equation 7)

Therefore,

$$F_a = 6.42N$$

Total resistance losses(TRL):

$$TRL = Rolling\ Resistance + Aerodynamic\ Drag$$

$$TRL = \mu mg + \frac{1}{2}\rho A V^2 C_d \quad \rightarrow(5)$$

Where,

Coefficient of rolling resistance=μ= 0.04

Air density=ρ= 1.2

Flow velocity=V= 6.9 m/s

Area of frontal impact=A= 1.05 m^2

Drag coefficient=C_d= 0.7

Therefore,

$$TRL = 227\ N$$

Assuming,

Motor Torque= M_t= 6.36 Nm (motor torque provided 2kW motor at 3000rpm)

$$Torque\ on\ Wheel = W_t = Motor\ torque \times reduction\ ratio$$

$$W_t = 6.36 \times 10.45$$

$$W_t = 66.46\ Nm$$

Force at Max. speed:

$$Fs_{max} = \frac{W_t}{R} = 290.22\ N \quad \rightarrow(6)$$

Force by removing resistance

$$F - TRL = 290.22 - 227$$

$$F_r = 63.3\ N$$

$$Acceleration\ \ a = \frac{Fr}{m} = 0.12 m/s^2 \quad \rightarrow(7)$$

$$Time = t = \frac{V}{a} \quad \rightarrow(8)$$

$$t = \frac{6.9}{0.12} = 57.5\ s$$

Distance:

$$s = u.t + \frac{1}{2}at^2 \quad \rightarrow(9)$$

$$s = 198.4\ m$$

Therefore,

Total Tractive Effort (TTE):

The Total Tractive Effort is the total force required to move the vehicle.

$$TTE = RR + GR + F_a \quad \rightarrow(10)$$

In most conditions, the gradient force is neglected due to the assumed driving conditions,

$$TTE = 315.42\ N$$

Torque required at the wheel:

The torque that is required to overcome traction.

$$\boldsymbol{T = TTE \times r \times R_f} \quad \rightarrow(11)$$

where, $r = 0.299m(radius\ of\ tire)$

$R_f = 1.12$

$T = 80.9\ Nm = (without\ Gradient)$

Similarly, considering the Grade resistance,

$T = 310\ Nm\ (with\ Gradient)$

Max Torque:

It is necessary to check if the wheels of the vehicle are capable of transmitting the required torque. The maximum torque that can be transmitted through the vehicles wheels needs to be calculated and is given by:

$$T_{max} = \mu \times W_g \times r = 590\ Nm \quad \rightarrow(12)$$

For satisfactory performance of the vehicle,

$$T_{max} > T$$

$$590\ Nm > 310\ Nm$$

As this condition is satisfied, there will be no slipping of the wheels.

3.3 BRAKES:

The braking system is one of the most important systems in a vehicle as it is used to reduce the speed of the vehicle. It must function effectively for the driver's and passengers' safety. This section deals with the design of a braking system, Each wheel is equipped with four disc rotors in a hydraulic disc braking system. The vehicle braking is designed for two-seater cars.

Designing brakes for a multi-seater EV is especially complicated as a trade off has to be established in keeping the weight minimum to increase overall efficiency. Using motorcycle calipers in place of bulky calipers has many advantages. After a thorough comparison of brakes for front wheels of bikes and cars, it can be observed that they are interchangeable provided the design is thoroughly established under the working conditions . The use of bike brake calipers leads to significant weight reduction, without hampering performance. We have used Stainless Steel 321 in brake design.

Components of the braking system:

Hydraulic disc brakes have various components, these are the disc rotors and the brake pedals. Some of the major components include:

- **Disc rotors**: Outer diameter= 180mm, inner diameter= 140mm, with a thickness of 4.5mm.
- **Caliper**: Double piston calipers were selected. Piston diameter= 34mm front and rear.
- **Master cylinder**: The master Cylinder is used as it can be operated by a single brake pedal.
- **Brake pedal**: A brake pedal with a leverage ratio of 6:1 was used as it will decrease the driver's effort whilst increasing the output force.

Selection of calipers:

The dual-piston calipers are best suited because of their lightweight, easy availability and reliability.

Diameter of the disc= 180mm

Thickness of the disc= 4.5mm

Effective disc radius= 56.25mm

Master cylinders:

Single piston master cylinder with a bore diameter of 22 mm was selected with DOT 3 Brake fluid.

Considering, Gross weight of vehicle= 525kg

Front: Rear weight distribution = 40 : 60

Rear, OD= 190mm

Front, OD= 170mm

Master cylinder= 22 mm

Caliper piston diameter:

Front and Rear= 34mm

Brake pedal ratio= 6:1

Selection of Rotor :

Material envisaged for discs is Stainless steel 321.

The torque required to stop the vehicle, Tb is the torque dependent upon the wheel dimensions and dynamic weight transfer of the vehicle. The following expression gives the braking torque.

$$T_b = \frac{W_t}{2} \times \frac{D_w}{2} \times g \quad \rightarrow(13)$$

Where, D_w = Diameter of tyre

W_t = Dynamic axial weight

When a vehicle traveling at a particular speed is suddenly brought to rest, the frontal suspension jolts whereas the rear experiences a rebound effect. The reason for this is that the weight of the rear axle shifts to the front axle, this is known as the dynamic weight transfer. It is given by the expression:

$$W_t = \frac{mxg}{b} \quad \rightarrow(14)$$

Where,

W_t = Dynamic weight transfer.

h = center of gravity from the ground.

m = Mass of vehicle (Kg).

Caliper pressure generated= 800 PSI based on the manufacturing catalogue for Karizma ZMR.

P_a =5515200 N/m2

h = 300mm= 0.3m

m=525 Kg

g = 9.81

b = 2178mm(wheel base)

$$W_t = \frac{mxg}{b}$$

$$W_t = \frac{0.3\ X\ 525}{2.175} = 72.41\ Kg$$

By applying the above formula,

$$T_b = \frac{W_t}{2} \times \frac{D_w}{2} \times g$$

$$T_b = \frac{72.41}{2} \times \frac{.405}{2} \times \frac{9.81}{1}$$

$$T_b = 71.922\ N$$

Torque generated by the caliper on the rotor:

$$T = \frac{P \times f \times \pi \times (D^2 - d^2\ ) \times d}{4} \quad \rightarrow (15)$$

Where ,

$P = 5000000\ N/m^2$

$Pad\ Friction, f = 0.4$

$d = Inner\ diameter\ of\ rotor\ contact = 140\ mm$

$D = Outer\ diameter\ of\ rotor\ contact = 180\ mm$

Therefore,

$$T = \frac{5000000\ x\ 0.4\ x\ 3.142\ x\ (0.180^2\ -\ 0.140^2)\ x\ 0.140}{4}$$

$$T = 2814.867\ Nm$$

Assuming the pad covers 360º on the rotor disc on a single side. However, the pad only covers a small fraction of the rotor disc. Therefore,

$$Pad\ Fraction = \frac{pad\ contact\ angle}{360}$$

$$Pad\ Fraction = \frac{30}{360} = \frac{1}{12}$$

Actual $T_r = T \times Pad\ fraction$

$T = 2814.867^{1/12} = 234.5722\ Nm$

Factor of safety,

$$FOS = \frac{Torque\ generated}{Torque\ required} = \frac{234.5722}{82.93} = 3.26$$

Hence, the design is deemed safe.

Calculations for stopping distance:

Kinetic energy of vehicle is,

$$K.E. = \frac{m \times v^2}{2} \quad \rightarrow (16)$$

$$K.E. = \frac{525\ x\ 7^2}{2}$$

$$K.E = 12862.5\ J$$

The maximum friction force,

$$Ff_{max} = \mu mg \quad \rightarrow (17)$$

$$Ff_{max} = 0.7 \times 525 \times 9.81 = 3605.17\ N$$

Where, μ = friction coefficient

m =mass of the vehicle

g =9.81 m/s²

Deceleration of the vehicle can be given through, $a = \frac{F}{m}$

Where, Ff_{max}= Maximum friction force

m =gross mass of the vehicle

$$a = \frac{3605.17}{525} = 6.866\ m/s^2$$

(c) Time taken to stop the vehicle

$$t = \frac{v}{a} = \frac{7}{6.866} = 1.02\ s$$

Distance covered by the vehicle in 5 seconds is the stopping distance, and is :

$$= V \times 5 = 7 \times 5 = 35m$$

Total stopping distance= $V \times reaction\ time \times \frac{V^2}{2\mu g}$ →(18)

$$= 7 \times 2.5 \times \frac{7^2}{2\ x\ 0.7\ x\ 9.81}$$

$$= 62.43\ m$$

Calculations for braking force and heat flux:

Tangential braking force is given by:

$$BF_t = \frac{Kinetic\ energy}{stopping\ distance} \quad \rightarrow (19)$$

$$BF_t = \frac{12862.5}{62.43}$$

$$BF_t = 206.03\ N$$

Tangential force on each wheel

$$F_t = \frac{BF_t}{4} \quad \rightarrow (20)$$

$$F_t = \frac{206.03}{4}$$

$$F_t = 51.507\ N$$

Braking torque on wheel,

$$T_w = F_t \times R \quad \rightarrow (21)$$

$$T_w = 51.507 \times 0.2025 = 10.43\ Nm$$

where, R = radius of tyre

Hence, effective rotor radius is:

$$R_e = \frac{rotor\ outer\ radius}{2} - \frac{rotor\ inner\ radius}{2}$$

$$R_e = \frac{180}{2} - \frac{140}{2} = 77.5\ mm$$

Clamping force, $C = \frac{T_b}{2\ x\ \mu\ x\ R_e}$ →(22)

$$C = \frac{82932}{2\ x\ 0.7\ x\ 77.5} = 764.35\ N$$

Heat flux:

In the braking system, mechanical energy is transformed into calorific energy.

Heat generated at the disc is equal to the Kinetic energy of the braking system.

$$H_g = K.E$$

$$H_g = m_d \times C_p \times \Delta t \quad \rightarrow (23)$$

where,

C_p =Specific heat

Δt =temperature difference
m_d = mass of the disc
Therefore, $H_g = 0.4 \times 460 \times \Delta t$

$$\Rightarrow \Delta t = \frac{12862.5}{0.4 \times 460} = 69.9℃$$

3.4 STEERING:

In terms of driver-vehicle interaction, the steering is by far the most important feedback system. Proper steering is needed for effective control of the vehicle and it should be precise. It is also necessary that the system be efficient, compact, and lightweight. Additional requirements include a precise perception of road surface for the driver and assistance in restoring the wheels to a straight-forward position. Rack and pinion steering may be chosen as one of the two basic steering techniques because of its availability, broad use, and inexpensive cost. As from the basic concept of rack and pinion, as the steering wheel turns, it turns the pinion gear, which then moves the rack in the steering system; this mechanism is encased in a metal box. A connecting rod at both ends of the rack connects the swivel ball and the steering arm when rotated moves the wheel. The key advantage of this mechanism is excellent steering control and feedback.

Design parameters of the steering system:

Vehicle width a_w =1450mm
Wheelbase b =2175mm
Track width c =1100mm (refer diagram)
Turning radius = 3000mm

$$R = \frac{b}{sin\Theta} + \frac{[a_w - c]}{2} \quad \rightarrow(24)$$

$$\Rightarrow 118.11 = \frac{85.63}{sinØ} + 6.88$$

$$\Rightarrow sinØ = 0.76$$

$$\Rightarrow Ø = 49.46 \;°$$

Also, $cotØ - cot\theta = \frac{c}{b}$ →(25)

$$\Rightarrow cot(49.46) - cot\theta = \frac{43.30}{85.63}$$

$$\Rightarrow \theta = 36.23°$$

Therefore, Total steering angle

$$T_{sa} = Ø + \boldsymbol{\theta} = 85.69° \quad \rightarrow(26)$$

Total angle turned by steering wheel

$$T_w = \frac{track\ width}{2*\pi*rp} = \frac{4.48}{2*\pi*0.53} = 484.33^o \quad \rightarrow(27)$$

Steering ratio, $S_r = \frac{T_w}{T_{sa}}$ →(28)

$$S_r = \frac{484.33}{85.69} = 5.65:1$$

Ackerman inside angle,

$$\beta = tan^{-1}(base \times [\frac{base}{tan\beta} - width]^{-1})$$

→(29)

$$\beta = tan^{-1}(85.63 \times [\frac{85.63}{0.732} - 43.30]^{-1})$$

$$\beta = \mathbf{49}°$$

Now, ackerman, $\% = \frac{(inside\ angle)}{ackerman\ inside\ angle\ \beta} \times 100$ →(30)

$$\Rightarrow \% = \frac{49.46}{49} \times 100 = 100.36\%$$

3.5 MACPHERSON STRUT AND LEAF SPRING SUSPENSION:

Suspension system consists of tires, springs, shock absorbers and linkages that create connection between the vehicle to its wheels and allow relative motion between them. The systems must support both road handling and ride quality, which are always at different levels with each other. The configuration of suspensions involves finding the right compromise between all the components to ensure the best shock absorbing quality, which in turn results in higher comfort. It is important for the spring suspension to keep the wheel in touch with the road surface at all times because all the opposite reacting forces acting on the vehicle do so through the contact area of the tires. The design of front and rear suspension of a vehicle may be different depending on the type of vehicle.
Suspensions play a very important role in any automobile. We know that suspension systems used in vehicles reduce shocks and vibration of both reaction forces and the vehicle. It was decided to choose an independent suspension system for each wheel. The front suspension system is a MacPherson strut as it is easy to assemble and is lightweight. The rear has a leaf spring suspension and it was chosen as the vehicle needs to carry heavy loads. This suspension is highly reliable, requires no maintenance and can be used in rugged terrain.
Using Lotus Shark, we simulated and analysed that MacPherson Strut and established the castor angle and Damper characteristics. The roll, steer and bump of the suspension were closely simulated to establish the vehicle feedback when driving in the different terrains.
the analytical calculation for the front suspension are as follows :
m (Gross weight)=525Kg
weight on front suspension is 40% of total weight
considering weight ratio 40:60

$$525 \times \frac{40}{100} = 210Kg$$

i.e. wt on front suspensions = 210kg
let FOS be 2 therefore,
wt on front suspension = 420
wt on single strut= 210
Force acting in the spring P= 2060N
Assuming spring index C= 10
Through iteration we found that,
Diameter of coil (D)= 100mm
coil diameter (d)= 10mm

and number of turns n= 8

Wahl's factor, $K = \frac{4C-1}{4C-4} - \frac{0.615}{C} = 1.021$ →(31)

Shear stress, $\tau = \frac{8\times K\times P\times D}{\pi\times d^{3}} = 535.5\ MPa$ →(32)

Material considered is spring steel which has shear strength of 1380MPa, thus the dimensions assumed are safe.

Solid length of $L_s = n \times d = 8 \times 10 = 80\ mm$

Free length of spring, $L_f = L_s + \delta + (\delta \times 0.16)$

where δ is the Max Compression,

$$\delta = \frac{8\times P\times D^{3}\times n}{G\times d^{4}} = 83\ mm$$

→(33)

therefore, the Free length of spring is

$$Lf = 80 + 83 + (83 \times 0.16) = 176.3\ mm$$

In the below section, the figs shows the simulation of the suspension in Lotus shark software. The roll angle will be reduced if both front and rear rebound damping is increased. The roll rate is reduced for all variations except for that of rear compression where it will increase.

Mono Leaf spring design :

Mono leaf springs are the most simple form of springs, mostly used in the automotive world. Automobile suspension systems are made out of springs that have a simple and basic role in absorption of energy, vehicle motion and driving. So spring performance design plays an important role in the improvement of car dynamics. There is an increased rate in the replacement of steel- leaf springs with composite leaf springs due to high strength to weight ratio.

so we have decided to use ,

Material used : EN 47

Total length eye to eye, $L = 965mm$

Width, b= $45mm$

Thickness, t= $30\ mm$

Camber height = $125\ mm$

Gross weight, m= $525\ Kg$

Therefore,

Laden weight on each leaf spring

weight on single spring, $m_s = 157.5\ kg$

Total Force applied, $F = m_s \times g$

$F = 157.5 \times 9.81 = 1545.075\ N$

Design load, $P = n \times F$

$P = 3 \times 1545.075$

$P = 4635.225\ N$

'n' is factor of safety= 3

Maximum stress induced in full length leaves,

$$\sigma_f = \frac{18\times F\times L}{b\times t^{2}\times(N_f+N_g)}$$

→(34)

$$\sigma_f = \frac{18 \times 1545.075 \times 965}{45 \times 30^2 \times (2+3)}$$

$$\sigma_f = 132.5331\ N/mm^2$$

Deflection of the spring,

$$y = \frac{12\times F\times L^3}{b\times t^3\times E(2N_f+3N_g)}$$ →(35)

$$y = \frac{12 \times 1545.075 \times 965^3}{45 \times 30^3 \times 2 \times 10^5 \times (5)}$$

$$y = 13.71\ mm$$

Stress induced under the applied load,

$$\sigma = \frac{6\times F\times L}{N\times b\times t^2}$$ →(36)

$$\sigma = \frac{6 \times 1545.075 \times 965}{1 \times 45 \times 30^2}$$

$$\sigma = 220.885\ N/mm^2$$

where,

No. of leaves, $N = 1$

No. of full length leaves, $N_f = 1$

No. of graduated leaves, $N_g = 1$

All the calculations done for a single leaf spring- required two springs.

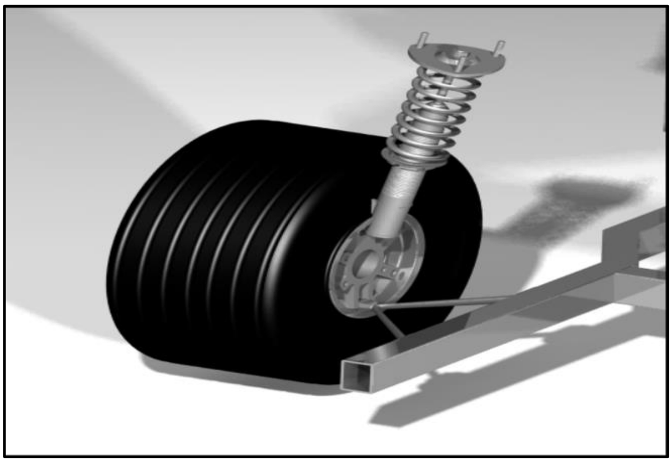

Fig-3: McPherson Suspension (Front)

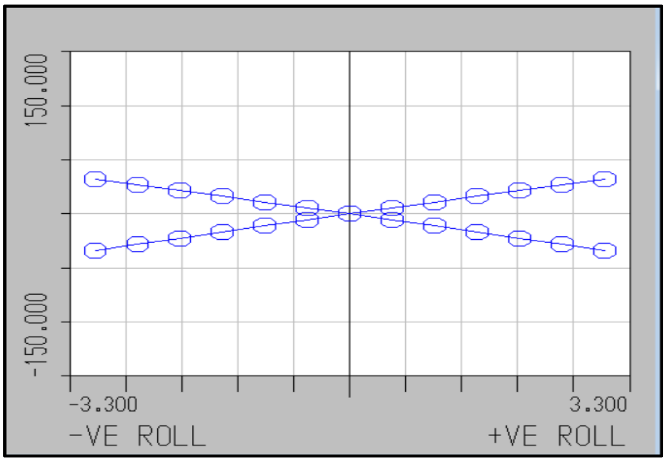

Chart-1: Front Damper characteristics

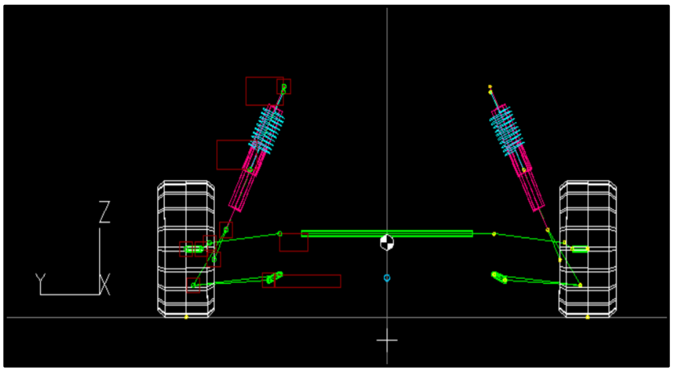

Fig-4: Front Suspension visuals simulated in Lotos Shark

3.6 FIXTURES:

This section details all the fixtures used in the vehicle to fasten all the connections.

- ➔ The load bin will be fixed to the chassis using M16 Nuts and Bolts.
- ➔ The side railing is joined using stainless steel plates of 4mm thickness using M12 Nuts and Bolts.
- ➔ Most of the other components are joined using M14 Nuts and Bolts of Stainless Steel.

3.7 MOTOR:

Motor provides the driving force to the EV. The operation of EV's directly depends on the characteristics of the electrical motor. These characteristics and the performance of the motor are determined by the torque-speed and power-speed characteristics.

Motor type: Brushless DC motors are being utilised in electric cars as they are traditional and offer smooth and stable power production with high power. As the high power winding is put on the stator side and the excitation is done by the rotor using a permanent magnet, which is often referred to as inside out architecture makes the structure strong compared to brushed DC motors.

The name Brushless DC suggests that the standard commutator and brush arrangement is not required here. Due to the electronically controlled commutation these BLDC motors are maintenance free. Starting torque is high in BLDC. Impressive efficiency of around 95-97% is delivered by these motors. Therefore we came to a conclusion that a BLDC motor would suit the best for our EV.

Motor Specification:

As the gross weight of the vehicle is found to be around 525 Kg .The motor shaft must provide 6.36Nm of torque at a rated speed of 3000 RPM to drive the vehicle as seen in section 3.2.

Power of BLDC motor is given by: Power

$$P = \frac{Torque \times Speed\ in\ RPM \times 2 \times \pi}{60} \quad \rightarrow (37)$$

$$P = \frac{6.36 \times 3000 \times 2 \times 3.14}{60}$$

$$P = 1.99\ kW$$

Therefore to provide the required power output a motor of 2kW, 48V will be used. The speed of the motor according to the given problem statement will be 3000 rpm.

Table-4: Motor Characteristics

Rated Power	2000kW
Rated Speed	3000rpm
Rated Voltage	48V
Rated Current	41.66A
Rated Torque	6.36Nm
Motor Size	17x12x11 cm
Weight	4.2kg

Motor Controller:

Motor Controller is the main control unit of Electric Vehicle. The EV controller is an electronic device that operates between the batteries and the motor to control and maintain the speed and acceleration regulating the energy flow from the battery. The speed is continuously regulated by the vehicle driver via the pedal throttle. The driver command acts as a speed reference input on a Proportional-Integral outer-loop motor speed controller. Apart from regulating the power to the BLDC motor, it also has secondary inputs like Keyswitch to turn on the EV and various power outlets for throttle, headlights, tail lights and indicators. EV Motor Controllers are also capable of handling over voltage and currents other than external protection circuits. Another function of the motor controller is the Regenerative Braking.The Motor controller helps in the process and uses the electricity produced from the energy produced by brakes to recharge the batteries, instead of letting it go waste.

Table-5: Motor Controller characteristics

Voltage	48V
Continuous Current	20.8A
Peak Current	80A
Throttle potential	5V

Under-voltage protection	40-42V
Current limiting potential	39-41V
Temperature Range	-20°~ 45°C
Weight	525g
Power	2000W

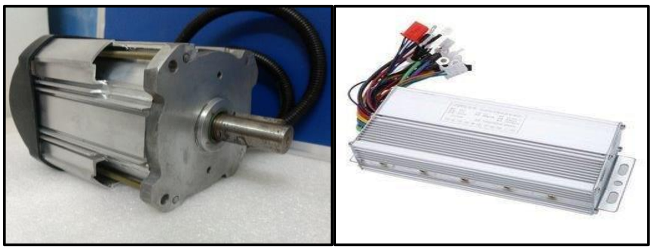

Fig-5: BLDC Motor and Motor controller

3.8 BATTERY:

One of the most important parts of an electric utility vehicle whether it is solar powered or not, is the batteries. The batteries will be used to power every aspect of the cart, from the electric motor to all of the onboard electronic systems. More importantly, for most solar electric systems there is a battery bank that is used to store the energy captured by the PV panels to be used when the system is off the grid or is not in prime condition. For our case, the batteries will be getting energy from both the PV panels and the wall charger and then being converted and used to power the cart and its subsystems.

Vehicles along with many small solar electric systems are usually equipped with deep cycle batteries. The Deep cycle batteries are constructed in such a way that they can be discharged as low as 80% of their total capacity without suffering any internal damage. One of the reasons deep cycle batteries can be discharged to such a degree is because they have thicker plates. Plate thickness in a typical electric vehicle battery is around .07” to .11” thick. In small solar electric systems vehicle batteries are widely used for power storage. Because utility vehicle batteries are typically deep cycle batteries capable of delivering continuous service with numerous charge/discharge cycles and ensure a good lifespan. This is a key component in solar power systems because the PV panels will be constantly charging the batteries, while the batteries are also being depleted.

Type of Battery: The performance of the EV is sharply related to the design of the battery pack that powers the vehicle and must be able to offer sufficient current to the motor over a prolonged period of time. Several different battery types are being used in EVs based on their application. The following factors have been considered in battery selection:

- **Performance**:This depends mostly on nominal voltage, capacity, depth of discharge and operating temperature. High temperature reduces the battery life span, at the same time low temperature decreases the battery’s performance.
- **Safety**: It takes plenty of power to drive an EV that should be delivered harmlessly. The chosen battery should be stable and less prone to mishaps.
- **Life span**: A battery which can give a high number of charging and discharging cycles would be on top priority. The battery life cycle is governed by a variety of factors, such as the battery’s intended usage, operating circumstances, and the depth of battery discharge.
- **Specific Energy:** Energy density represents battery capacity in weight (Wh/kg) and the amount of energy stored per unit mass. In applications where a long runtime is not required, moderate specific energy is required.
- **Cost**: Battery price is one of the biggest challenges in EV design because it takes up a major chunk of the total EV budget, hence making it important to choose the right battery.

Fig-6: 32650 $LiFePO_4$ cell

Battery:

Comparison between Lithium Iron Phosphate ($LiFePO_4$) and Lithium ion batteries, showing why Lithium Iron Phosphate is a better choice,

Table-6: Comparison between batteries

	$LiFePO_4$	Li-ion ($LiCoO_2$)
Nominal Voltage	3.2 V	3.6-3.7V

Charge(C-rate)	1C	0.7-1C
Discharge(C-rate)	1-25C	1-3C
Cycle life	1500-2000 cycles	500-1000 cycles
Thermal Runaway Temperature	270°C Very safe battery even if fully charged	150°C Full charge promotes thermal runaway
Specific Energy	90-120Wh/kg	150-200Wh/kg
Shelf Life	350 days	300 days
Environmental impact	Nontoxic LiFePO4	LiCoO2 is toxic and dangerous.

Battery Specifications:

Time taken by the vehicle to cover the desired range at maximum speed is given by:

Time, $T = \frac{\textbf{Range}}{\textbf{Maximum Speed}}$

$$T = \frac{30\ km}{25\ km/hr} = 1.2\ hours \quad \rightarrow(38)$$

As calculated in section 3.6 the power rating of the motor is 2kW.

Therefore the minimum amount of energy the battery should provide to run a 2kW BLDC motor for 1.2 hours is:

$$E_t = Power \times Time \quad \rightarrow(39)$$

$$E_t = 2kW \times 1.2\ hours$$

$$E_t = 2.4\ kWh$$

The above Energy value is the amount which will be completely consumed by the load. Hence considering the Depth of Discharge as 80% ($LiFePO_4$). Total Energy contained by the battery to safely charge and discharge is:

$$E_p = \frac{E_t}{0.8} = 3\ kWh \quad \rightarrow(40)$$

Current Rating of the Battery ,

$$C_b = \frac{3kWh}{48V} \quad \rightarrow(41)$$

$$C_b = 62.5\ Ah$$

Number of 32650 $LiFePO_4$ cells required in Series

$$N_s = \frac{Battery\ output\ voltage}{Nominal\ voltage\ of\ 32650\ LiFePO_4\ cell} \quad \rightarrow(42)$$

$$N_s = \frac{48V}{3.2V} = 15\ cells$$

Number of 32650 $LiFePO_4$ cells required in Parallel

$$N_p = \frac{Battery\ Current\ Rating}{Current\ Rating\ of\ 32650\ LiFePO_4\ cell} \quad \rightarrow(43)$$

$$N_p = \frac{62.5\ Ah}{6\ Ah}$$

$$N_p = 10.41 \simeq 11\ cells$$

The battery pack will be made of 2 units connected in parallel configuration. Each unit will be a cluster of ninety *32650 $LiFePO_4$* cells. To achieve the required current rating of 31.25 Ah, six cells of 6Ah form a block in which they are connected in parallel and fifteen such parallel blocks are connected in series to add up the voltages to get 48V. Both units are monitored by two separate BMS. The division of the battery pack is done in order to reduce the number of cells in the parallel pack so they can be inspected more efficiently.

3.9 BATTERY MANAGEMENT SYSTEM [BMS]:

Any electric vehicle's primary component is the battery. To keep the battery healthy, multiplex parameter monitoring and management is required. A battery management system is in charge of this daunting challenge. The BMS examines and controls parameters such as battery parameters, safety, charge rates, and longevity. This ensures maximum performance from the battery and also increases its life.

For a battery to function efficiently the BMS takes care of the following factors:

- **Discharging control:** The operating range of a typical $LiFePO_4$ is 2.5-3.6V. So a cell should not discharge below 2.5V else it will cause discontinuity and can damage the cell which will disturb the working of the entire battery pack.
- **Charging control:** Overcharging of cells increases the risk of thermal runaway. Though $LiFePO_4$ batteries are fairly resistant to undergo thermal runaway. It is still important to take care of the battery. The BMS uses a 2 stage charging method. The first stage is constant current, next stage is constant voltage and both the voltage and current should not exceed the permeable limits.
- **Cell Balancing:** In a pack of cells each cell should charge at the same rate and attain full charge at the same time, imbalanced packs are hazardous for the vehicle battery as it causes internal discharging of cells which can significantly reduce the battery life. There are 2 types of cell balancing passive and active, in passive cell balancing the idea is to pass all the excess charge through to the load resistor to maintain the cells voltage equal to other cells, the disadvantage of this technique is

that it only helps with the problem of overcharging but while the cells are discharging if a cell reaches its limit early then BMS will cut off the supply thus the remaining charges in battery are gone to waste but this method is very cheap as compared to active technique and in active cell balancing cells with higher voltages are used to charge cells at lower voltages this is better when compared to passive cell balancing as it also solves the problem of discharging at the same value.

- **State of charge:** The current level of charge remaining in the battery in relation to its capacity is referred to as the battery's state of charge. Its limit is defined by the depth of discharge. For $LiFePO_4$ battery the maximum DoD is 80%.
- **Temperature monitoring:** Temp of the battery is directly correlated to performance of the battery. The battery temp increases when the battery is being charged or discharged hence should be constantly monitored and maintained within the safety limits.
- **State of health:** As the battery ages the performance of the battery depletes. If a high current is drawn, discharge is much quicker and also the temperature rises.

After acquiring the battery and current requirements from section 3.7 we are using a 15S $LiFePO_4$ BMS which supports up to 50A continuous current. The BMS comes with 2 temperature sensors to keep a track of the temperature at two different points in the battery pack. The BMS cut off the battery supply from the main system in case of overcurrent of order 100-120A. Additionally the chosen BMS can be coupled with a Bluetooth module and the inspected factors can be seen on a mobile application.

3.10 SOLAR PANEL:

A photovoltaic (PV) or thin silicon film panel is mounted on top of the car roof, or a PV panel is used as the roof itself, to power solar EVs. Solar Panels are an effective way to harness energy from the sun and help power the utility vehicle along with the charge from a wall outlet. The vehicle we obtained for this project is already equipped with two Grape Solar at High Efficiency Mono-Crystalline Photovoltaic panels. Unfortunately, these two panels alone will not be strong enough to completely charge the battery bank, but the idea is that they will at the least help prolong the discharge time of the batteries. Realistically, this should considerably help with the power consumption from all of our onboard electronic subsystems as well. The two roof-mounted solar panels will be used to convert the photonic energy from the sun into usable electricity. These panels will be used to charge the batteries in order to provide power to the utility vehicle. In order to harness as much energy as possible from these solar panels, the wiring configuration to the motor and subsystems is critical. Wiring these panels in series yields the most voltage to charge the batteries. Another option would be to wire these panels in parallel to produce a higher current, however; this could cause power loss due to one of the panels receiving less sunlight.

A Monocrystalline Type Solar panel is used which has higher efficiency as compared to other panel types (i.e 20% whereas other panels have around 15%-17% eg: polycrystalline type).

We will be using a 300W/60V solar panel with dimensions as 168.4cm x 92.2cm which can easily fit on our EV. Higher wattage will charge faster but it will occupy more space and weigh more.

4. ELECTRONICS:

Charge Controller: The type of Charge Controller we will be using is Maximum Power Point Tracking (MPPT), which is 30% more efficient than PWM controllers, the maximum power point tracker sweeps across the panel voltage to locate the optimal or best combination of voltage and current for maximum power generation. The MPPT is deviced to continuously monitor and fine-tune the output voltage to generate maximal power in different weather conditions. The solar controller auto severs the output when the intensity of sunlight is not adequate.

SMPS charger: Switch Mode Power Supply shows higher efficiency than conventional rectifier circuit. The rectified mains are broken up into small pulses by SMPS, which charge a capacitor. The pulse width can be varied to control current demand and regulate output voltage. They are capable of handling high input voltage fluctuations and can provide constant current as well as constant voltage charging hence able to charge in CV-CC configuration. The rating of the charger used to charge the battery is 48V 15A SMPS charger.

Microcontroller Unit: The MCU takes control of all the minor activities running throughout the vehicle as an alarm unit, communication between components and safety measures.

Electronic Thermal Overload Relay: Thermal overload relays are connected in the current path. When the current value surpasses a fixed threshold for a certain amount of time, a thermally triggered mechanism opens the relay contacts to interrupt current flow from the battery. Trip class of a thermal overload relay determines the amount of time for which the overload occurs before the relay reciprocates the change. Electronic sensing of current makes these relays more accurate and avoids false tripping.

Wires: The majority of power flow in the EV takes place between the Battery, Motor Controller, Motor and the charger. To accomplish this task of withstanding high currents without heating up, high grade silicone wires of 4-6 AWG rating are used. The silicone rubber coating makes them fire resistant and ensures circuit integrity.

Regenerative Braking: The braking system in a vehicle is a disc arrangement that helps to slow down the vehicle and converts the kinetic energy into electric energy via regenerative braking. Basically in the braking system friction is produced between the brake pads and the disc, this is the kinetic energy converted to heat which goes to waste. However, in regenerative braking, some of the energy is recovered, which is used to charge a battery. The small scale electric vehicle has a small drivetrain technology that harvests a lesser amount of braking energy through regenerative braking. This system has been brought up with low cost, Since it is designed to store only a relatively small capacity of the braking energy, and for a short period.

Calculations:

Work done by the brakes, Dk (*D*k describes the energy dissipated during braking per unit time)

$V = Mean\ journey\ speed$

$V_o = Maximum\ speed\ without\ engine\ braking$

$$V = \beta \times {V_o}^{0.62} \times {V_{max}}^{0.45} \qquad \rightarrow (44)$$

$$V = 0.93 \times 18^{0.62} \times 25^{0.45}$$

$$V = 23.75\ km/h\ or\ 6.6m/s$$

Now, $$D_k = A \times \left(\frac{V}{{V_{max}}^{0.45}}\right)^{B} \qquad \rightarrow (45)$$

$$D_k = 9.61 \times \left(\frac{23.75}{18^{0.45}}\right)^{6.3}$$

$$D_k = 5226.86\ joules$$

A and B are standard constants: $A = 9.61 \times 10^{-6}$;$B = 6.3$

β : 0.93 for normal driving (according to our specified terrain of operation) on a plain path.

5. WIRING LAYOUT:

The diagram below describes in detail the entire wiring and connection layout for the Electric Utility Vehicle:

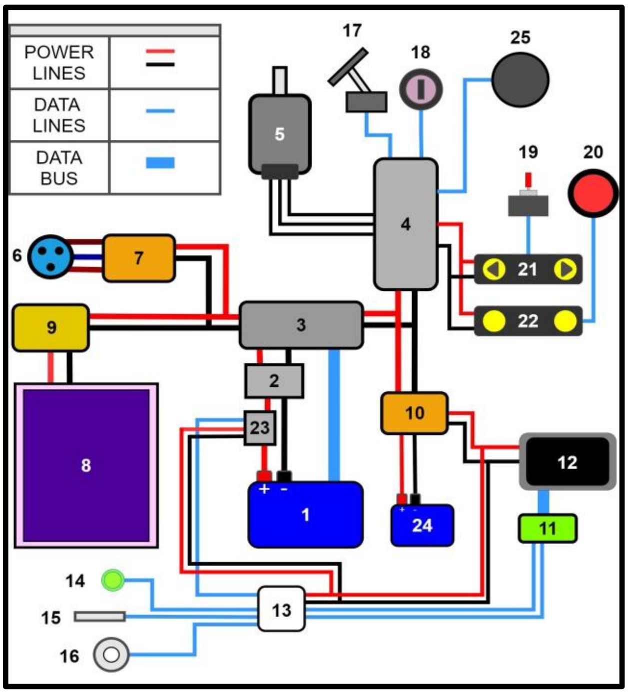

Fig-7: Wiring Diagram

Table-7: Components

Sr. No.	NAME	SPECIFICATION
1	Battery	48V 62.5Ah,15S6P configuration of 32650 $LiFePO_4$ cells.
2	DC Miniature Circuit breaker	120A breaking limit,10kA breaking capacity
3	BMS	48V 15S 50Amp separate port BMS
4	Motor Controller	48V 2000W Motor Controller
5	BLDC Motor	48V 2000W BLDC Motor,3000 RPM
6	IEC 60309 Industrial Blue	220V 16A 3Pin Connector
7	Charger	48 V 15A SMPS Charger
8	Solar Panel	300W/60V Monocrystalline Solar panel
9	Solar Charge	MPPT Solar charge controller

	Controller	
10	DC-DC Stepdown Converter	48V to 6V,3A Stepdown Converter
11	Touchscreen Display	7" Touchscreen Display
12	Display controller	-
13	Microcontroller Unit	MSP430G2553 Low power Microcontroller
14	Ambient Light Sensor	CJMCU-TEMT6000
15	Temperature Sensor	DS18B20 Waterproof Temperature Sensor
16	Odometer	Rotary Encoder
17	Pedal Throttle	-
18	Key Switch	-
19	Indicator Toggle Switch	6A SPDT Toggle Switch
20	Push Button	Self-Lock Non-Momentary Switch
21	Indicator Lights	12V Led Indicator Lights
22	Head Light	12V Led Headlights
23	Electronic Thermal Overload Relay	120A
24	Auxiliary Battery	12V 7Ah
25	Tyre brake set	Disc brakes

Fig-8: Isometric View of CAD Design

7. VEHICLE SIMULATION

MATLAB and SIMULINK were used to develop simulation blocks to simulate the vehicle's performance characteristics, battery performance and motor behaviour.

7.1 SOC v/s Discharge Current:

The graph below shows the State Of Charge (SOC) of the battery v/s the Discharge Current:

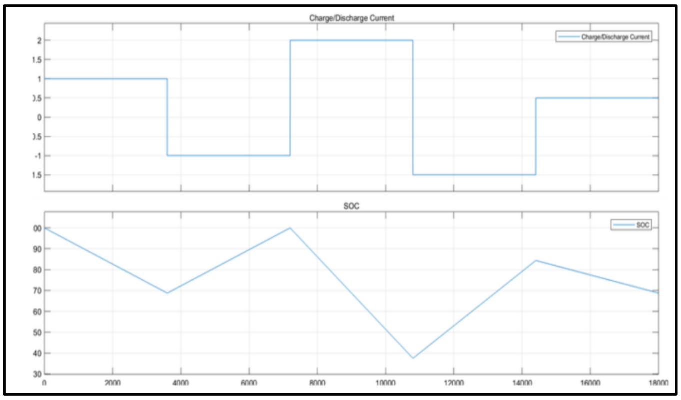

Chart-2: SOC v/s Discharge Current

7.2 SOC and Speed to 40kmph:

The graphs below show the variation of SOC and Mileage with respect to Time:

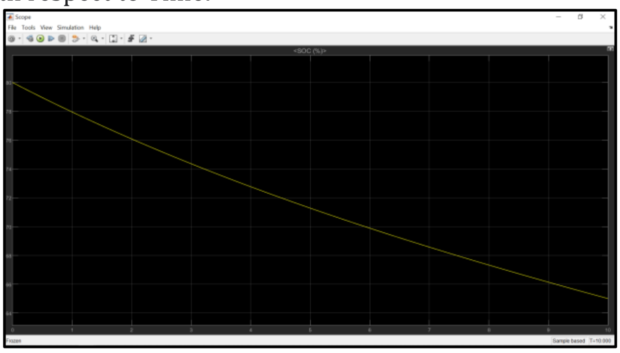

Chart-3: SOC v/s Time

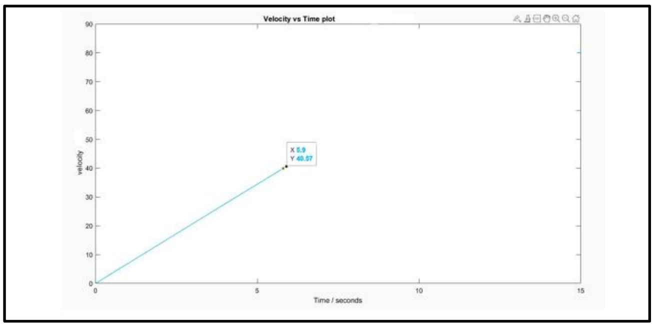

Chart-4: Time to 40kmph

7.3 SOC Estimation Circuit:

The SOC Estimation block used in SIMULINK is as follows:

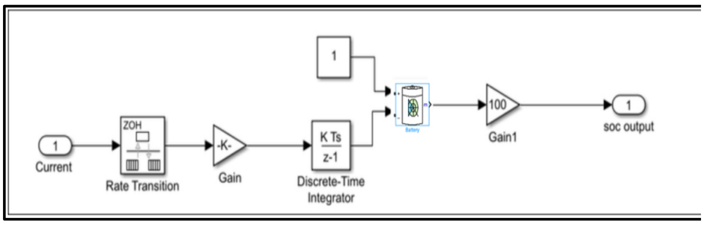

Fig-9: SOC Estimation Model

7.4 Average Motor Speed Characteristic graph:

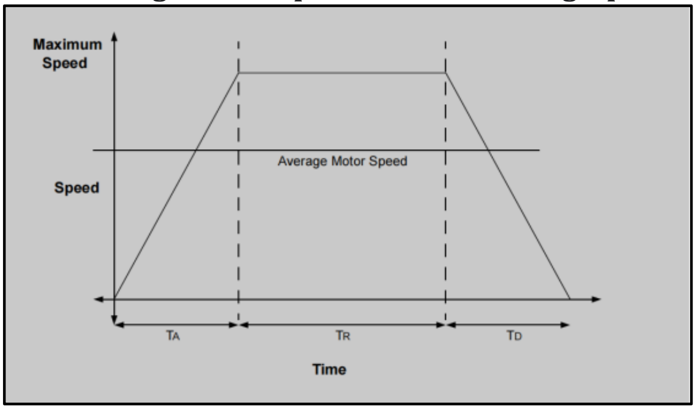

Chart-5: Average Motor Speed Characteristics

7.5 Power-Torque-Speed graph (Performance graph):

The graph below shows variation of Peak and Continuous Torque, Peak and Continuous Power with respect to Speed:

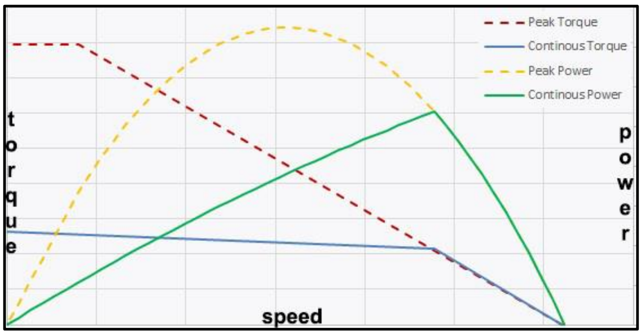

Chart-6: Performance graph

8. CONCLUSION

The Vehicle was designed and analysed to perform under any working conditions and terrain. Manufacturability and economic constraints were also kept in mind so that the most cost effective model could be developed. The EV was designed to be lightweight and to give improved range by the addition of an advanced Battery and BMS coupled with Solar panels. Electric Vehicles are non-polluting and have very few moving parts, eliminating the need for constant repair but in case the need arises for repair, the batteries, motor and other parts are easily accessible through hinged openings. The frame of the vehicle was designed to be robust enough to carry weights in excess of the specified gross weight. The loading bin was designed to have a carrying capacity of 540 L making it ideal for lightweight load carrying operations. Increasing pollution has led many countries to push for fully electric fleets to cut down on emissions. A lot of impetus has been put on electrifying passenger vehicles, but the challenges are entirely different for commercial vehicles as there are concerns about range, charging time and the required infrastructure. In this paper, an attempt has been made at designing a class of light utility vehicle that uses solar panels and regenerative braking to supplement power.

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