IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

CASE STUDY TO IMPROVE THE EFFICIENCY AND RANGE OF CONVENTIONAL ELECTRIC VEHICLES BY USING SOLAR ENERGY AS FUEL

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ABSTRACT:

In recent times fossil fuels are said to cause a lot of damage to the environment and have adverse effects on human life as well. Also, in the coming years fossil fuels are said to be replaced by alternative sources of energy which are much more efficient and have considerably less or negligible impact on the environment. The purpose of this paper is to devise a system capable of utilizing the freely available solar energy which would be used to power a battery-powered electric vehicle with improved efficiency and range. It is a step towards sustainable development by using resources that can replace conventional sources and meet the expectations. This system is designed as a country specific model i.e. it has been designed to run efficiently on Indian Roads considering the factors that can affect the performance of the same. The proposed system can be further modified as per country regulations.

KEYWORDS: Efficiency, Range, EV, Solar cell, DC, AC, Inverter, Structural Analysis.

INTRODUCTION:

The production and development of electric vehicles is increasing day by day in different parts of the World. Although in some countries like India, there hasn't been significant progress in the development of Electric vehicles. In developed countries like The United Kingdom, Germany, France the United States Of America, etc. there have also been considerable amount of increase in the production of Solar powered vehicles as a means to attain sustainable development. This research aims at developing an automobile system capable of converting solar energy available into significant useful charge in order to run a conventional battery-powered electric vehicle. Solar energy replaces the conventional sources like petrol and diesel, which can benefit in terms of increased range and reduced emissions. There is great future for environment friendly developments. The proposed system will not only be a boon to the transportation industry in the country, but it will also ensure minimal damage to the environment. As this is a country specific vehicle model, an attempt has been made to design for maximum efficiency, keeping in mind the various norms and parameters that may affect the vehicle performance.

LITERATURE SURVEY:

According to a recent research conducted by environmentalists, the contribution of automobile sector to the air pollution is about 23%. In order to reduce this, various automobile companies are coming up with electric and solar vehicles that may prove beneficial in the future. The processes required to develop a solar car are more or less the same as that of Electric Vehicles. The only difference lies in the Power rating and the conversion efficiency of the solar equipment used in the vehicle. According to various researches conducted by automotive enthusiasts and electrical engineers, it is implied that only a fraction of the available sunlight is converted to significant electricity by necessary equipment. This issue can be solved by changing the components of the solar cell which is to be used in the system. Even if the perfect solar cells were to be used, their conversion efficiency ranges from 20% - 24%. For the same purpose, the efficiency can be tweaked by either changing the constituents of the solar cell or by replacing conventional electrical equipments with much a more advanced system. According to our research, we have attempted to increase the efficiency by using an individual converter for each solar cell which will ensure that the conversion losses will be minimized. The roof of the vehicle is fabricated with various individual solar cells. As sunlight is one of the forms of energy which is freely available, it is used to charge the battery efficiently. This would lead to extended range of the vehicle and the energy supplied by the battery pack would be sufficient to power the electric components inside the vehicle. Also, the materials proposed for the body of the vehicle are selected in such a way that it results in overall weight reduction of the vehicle, compared to other vehicles in this

segment. The Aerodynamics plays an important role when it comes to acceleration and velocity of the vehicle along a desired path, which is taken care of as the vehicle is designed accordingly. Improved Batteries have been proposed for optimum performance of the vehicle at peak conditions. [1] [2] [6]

SCOPE OF THE PROJECT:

The project aims at efficient working of an electric vehicle powered by a group of solar cells. As solar cells not only charge the batteries, they are also used to run the motor and the auxiliary equipments which are included in an automobile. Normally, an electric vehicle with a range of 150-200 km could be perfect for Indian roads. However, considering various factors like the condition of roads, the availability of charging stations, and the amount of pollution, a design for solar car has been proposed. Also, keeping in mind that there has been a decent share of hybrid vehicles in the Indian market, the following idea is proposed so as to boost the development of EVs and solar-powered vehicles in the country. An attempt has been made to design a prototype capable of keeping up with the operator's expectations. As this vehicle is specifically designed for Indian Roads, it will overcome all the issues faced by conventional vehicles and may work in conjugation with the EV market in the country. The problem statement focuses on improving the efficiency and range of an (EV) by utilizing solar energy instead of hybrid technology. This research has been conducted on various types of vehicles in India to find out how they can be improved in terms of performance without having adverse effects on the environment. [1] [3] [12]

SELECTION OF COMPONENTS:

The components which have been selected for the proposed idea are on the basis of comparison with the existing marvels in the field of automotive technology. Tesla automotive, which is the World's largest EV producer, has been chosen for gaining insights in the research.

Following are the components selected for proper functioning of the proposed vehicle:

A. Battery Pack :

Fig 1: Lithium-ion Battery pack [15]

The battery pack which is proposed for this model is a Lithium-ion Battery pack consisting of Individual lithium-ion cells arranged in a series-parallel hybrid configuration to gain maximum power output.The individual cells used here are the 2170 lithium-ion cells, i.e. length of the cell =70mm and diameter of the cell = 21mm. This battery pack is the same as the one used in the Tesla Model S which consists of 16 modules having total 7000 individual cells. Hence, this battery pack is selected as it outperforms all the other variations in its segment. [6] [7] [10]

B. Solar cells:

Fig 2: Solar Panels (group of solar cells) on the roof of a solar powered vehicle [11]

The roof of the vehicle is covered with individual solar cells which are connected in series-parallel arrangement to make an entire solar panel. It is covered with a protecting glass layer so as to prevent it to have direct interaction with the surroundings and thereby increasing life. The individual solar cells have a rating of 0.5 volts and 8 Amp. These charge the battery while the vehicle continues to run on the road thereby increasing range. [11]

C. The Motor :

The motor used to drive the vehicle is a 3-Phase AC Induction Motor which is selected due to its minimum slip value when compared to other motors such as Brushless DC Motor or Wheel hub motor. The vehicle components are selected referring to vehicles that provide optimum performance under various loading conditions. [7] [10]

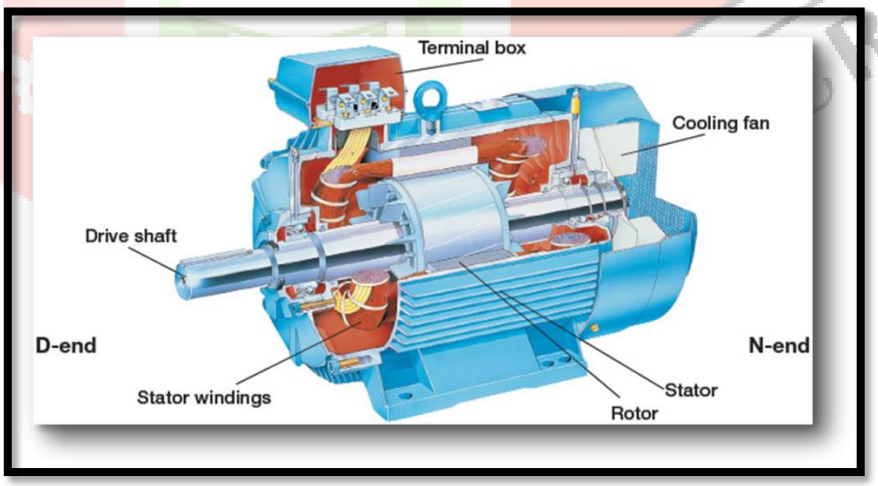

Fig 3: A three phase AC Induction motor [16]

D. The Inverter :

The inverter (as shown in Fig.4) plays a major role in any conventional EV vehicle and converts the DC current received by the battery to AC current which will power the motor. Selection of this component is a major task as it acts as the brain of the vehicle. By varying the input to the inverter i.e. the frequency of the alternating current (AC), the speed of the motor can be controlled directly. [7] [10] [11]

Fig 4: Energy flow through various components

E. Charge Controller :

The Charge controller (as shown in Fig.4) converts the input to the battery ensuring that overcharging or flow reversal of current doesn't take place. The charge controllers can store the charge and allow a fraction of it to be passed to the battery for its peak performance. [6] [7]

F. Converter :

The DC-to-DC Converter steps-up or steps-down the voltage received by the battery for efficient working of various electrical systems such as Infotainment System, Air-Conditioning System, and various systems that can be manipulated by the driver with the help of a switch. [7] [11]

Fig 5: DC Converter developed by Tesla Motors [10] [11]

MATERIAL SELECTION FOR VEHICLE BODY AND CHASSIS:

The materials proposed for the body and chassis are same and consist of Aluminium Alloys. In particular, the alloy selected is **Aluminium 7050** which is best in the 7000 series. It comprises of 6.2% Zinc, 2.3% Magnesium, 2.3% Copper, 0.1% Zirconium and 89% by weight of Aluminium. The advantage of Aluminium alloy over other materials is that it has a high power-to-weight ratio. It is supposed to be very light and is capable of handling various loads acting on it. Another alternative material could be the use of carbon-fibre body due to its weight reduction and high strength. [9] [12]

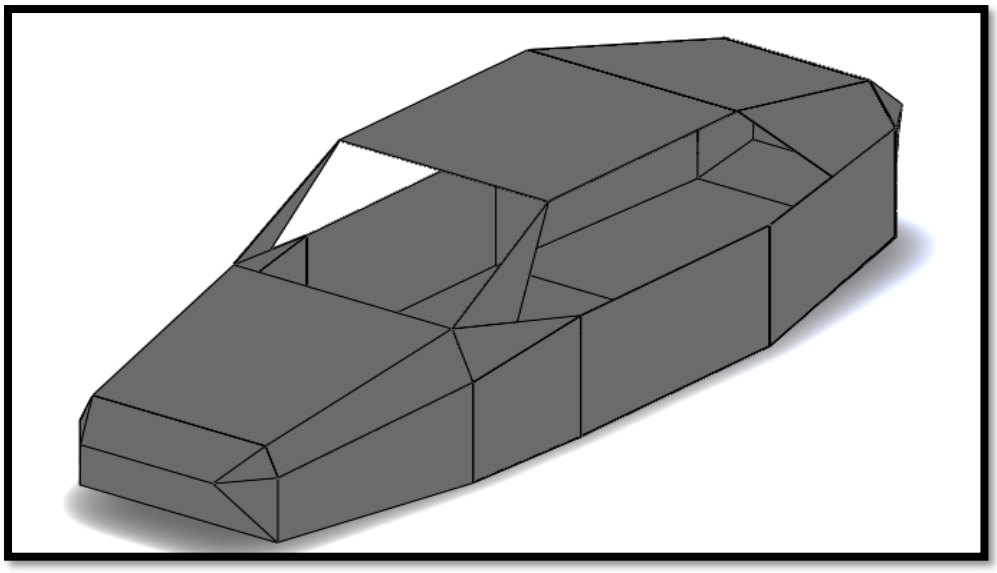

Fig 6: Isometric view of the design [11] [12]

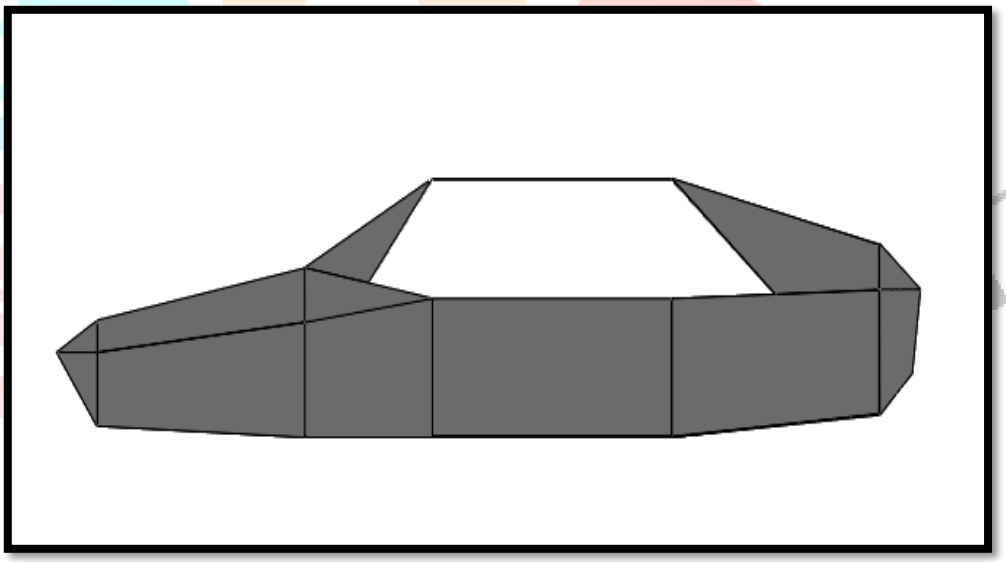

Fig 7: Side view of the vehicle [11] [12]

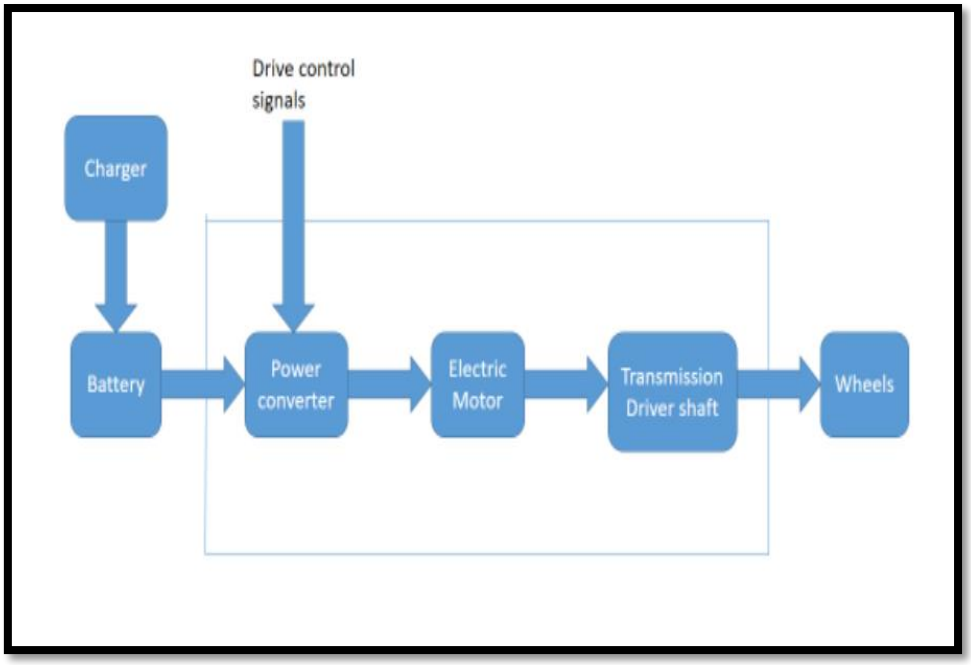

Fig 8: Powertrain Components [2] [4] [7]

ANALYSIS OF THE VEHICLE:

1. Calculation of Number of solar cells on the vehicle:

Length of the car = 4.89m

Width = 1.7m

Height from ground (Ground Clearance) = 1.5m

Wheelbase = 3.96m

According to the area available on the vehicle, the Number of solar cells to be used is calculated.

The number of solar cells to be incorporated in the available area on the bonnet, roof and the trunk are calculated as per design of the vehicle.

Bonnet Area:

Area of 1 solar cell = $0.023m^2$

Hence,

- No. of Solar Cells on the bonnet

  = (Area available one the bonnet)/ (Area of 1 solar cell)

  = 1.6129/0.023 = 70.126 ≈ **70 cells**

Roof Area:

- No. of Solar Cells on the roof

  = (Area available one the roof)/ (Area of 1 solar cell)

  = 1.95/0.023 = 84.78 ≈ **84 cells**

Rear Windshield Area:

- No. of Solar Cells on the rear area

  = (Area available over the rear windshield)/ (Area of 1 solar cell)

= 1.472/0.023 = **64 cells**

∴ **Total No. of solar cells on the vehicle =70+84+64 = 218**

These multiple solar cells connected in series-parallel circuit arrangements form individual solar panels.

2. ENERGY CALCULATIONS:

The battery selected for our model is a standard 75kwh Li-ion Battery Pack with a voltage rating of 350 volts.

- Solar Cell Specifications [8]

  Voltage = **0.5 V**

  Current = **8 Amp.**

Energy supplied by Solar Panel to the Battery is given in Watt-hour (Wh)

- Power generated by solar cells on bonnet

  = (V*I) *70 = (0.5*8)*70 = **280 Wh**

- Power generated by solar cells on roof and rear windshield

  = (V*I)*64 + (V*I)*84

  = (0.5*8)*(64+84) = **592 Wh**

Total power supplied by solar panels to the battery = 280+592 = 872 Wh

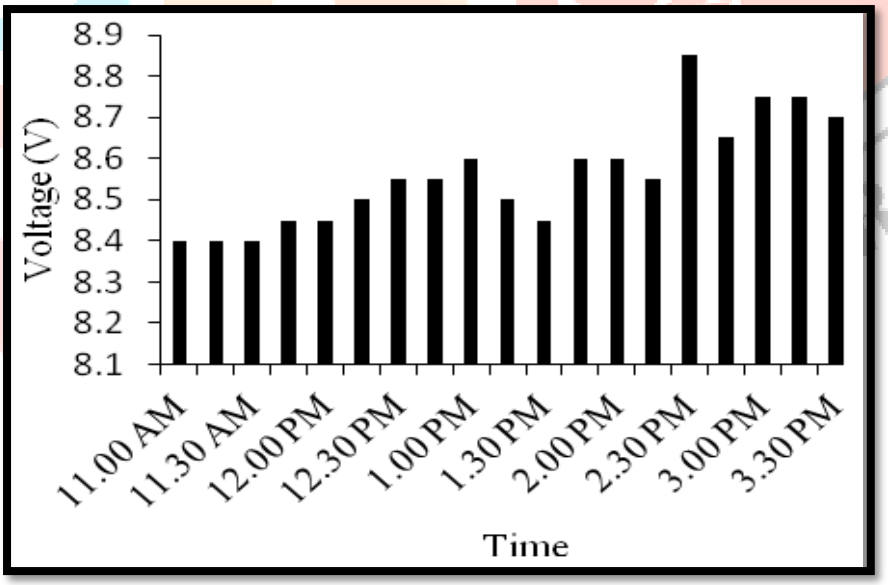

Fig 9: Graph of variation of voltage generated by solar panel with time [2]

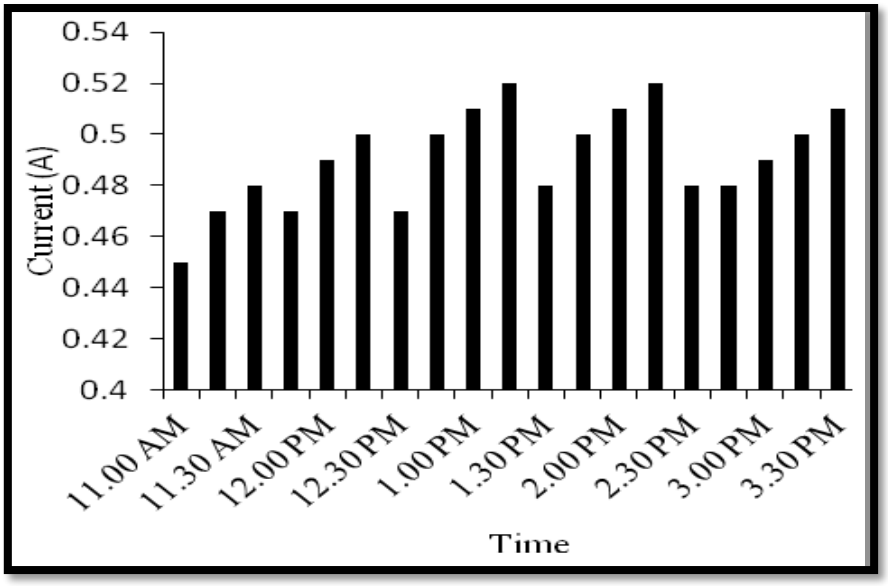

Fig 10: Graph of variation of current produced by solar panel with time [2]

The above graphs show peak sun hours in a day.

The total solar energy generated in an hour by natural sunlight is calculated:

Total Solar Energy Generated by Panels = 872 Wh

Considering System losses (factor = 0.75)

Total Solar power generated in an hour = 872*0.5= 654 Wh

Number of average peak sun hours in India = 5.5 hours.

Power Generated by solar panels per day = 872*0.75*5.5 = 3597 W/day

3. MOTOR CALCULATIONS:

Assumed Drag coefficient (Further verified by analysis) = 0.36

Transmission Ratio (Helical) = 9:1

Battery – 75 KWh

(Expected range = 250-350 km on Indian roads)

Motor:

The values have been recorded after comparison with various vehicles in the Electric vehicle segment. By conducting various tests on the electric powertrain, the following standard formulae are used to define certain parameters. [2][14]

$$F\,(max) = [(T\,(max) * N_T * \eta_T)/R_W] \qquad (1)$$

Where,

F (max) = Maximum Traction force provided by motor to run the vehicle

T (max) = Maximum Output Torque provided by the motor

N_T=Transmission Ratio

η_T = Transmission Efficiency

η_T = 94% = 0.94 (Considering losses)

R_W = Radius of Wheel

$$T\ (max) = [(F\ (max)*R_W)/\ (N_T*\eta_T)] \qquad (2)$$

F (max) = μ*N*9.81 …… [μ = 0.7(Dry Road)] [2]

N = Normal force due to weight of the proposed vehicle

μ = Coefficient of friction of the road

F (max) = 0.7*1100*9.81

∴ **F (max) =7553.7 N**

Fig 11: Standard tyre size [5][13]

According to Standard Wheel Size,

Wheel designation→ **(235/45R19)**

Where,

235 = section width of the tyre in mm

45 = Aspect Ratio

R = Radial Construction of tyre

19 = Rim Diameter in inches

∴ Radius of wheel (R_W)

= (Wheel diameter/2)*0.0254 [refer Fig.11]

= (27.3inches)*0.5*0.0254

∴ **Rw = 0.34671 m**

Also, Maximum Torque is found using Eq.2

Hence, on substituting the values we have,

T (max) = (7553.7*0.34671)/ (0.94*9)

∴ **T (max) = 309.56 Nm**

Now, the maximum velocity with which the vehicle can travel is given as:

V (max) = 120 km/hr.

[In accordance to the Regulatory body in India]

V (max) = (120*1000)/3600

∴ V (max) =33.33 m/s

At this maximum velocity of the vehicle, values of corresponding torque and power can be found out using **Eq.3** and **Eq.4**

$$(T_{req})_{at\ vmax} = \{[f_r W + 0.5*\rho*C_d*A_f*(V_{max})^2]*R_w\}/(N_T*\eta_T) \quad (3)$$

$$(P_{req})_{at\ vmax} = [(f_r W + 0.5*\rho*C_d*A_f*(V_{max})^2*V_{max})/\eta_T] \quad (4)$$

Where,

f_r = Coefficient of rolling resistance

W = Weight of the vehicle = 1100 kg (Considering all the components and auxiliaries)

ρ = Density of air = 1.22 kg/m^3 = 1.22*9.81 = 11.9682 N/m^3

C_d = Drag coefficient = 0.36 [As per simulation]

V_{max} = Maximum velocity of the vehicle

A_f = Frontal Area of vehicle

f_r = 0.02 (Std. Value on asphalt/gravel)

N_T=Transmission Ratio

η_T = Transmission Efficiency

η_T = 94% = 0.94 (Considering losses)

R_W = Radius of Wheel

By substituting the values in Eq.3 and Eq.4 we have,

Torque required at maximum velocity is 71.37 Nm.

Power required at maximum velocity is 61.74 kw.

Max Acceleration of the vehicle:

As the proposed vehicle is a Rear-Wheel-Drive Vehicle

Maximum acceleration = Tractive Force at rear/mass = (Fmax/2)/m = (7553.7/2)/1100

∴ Maximum **Acceleration of the vehicle = 3.43m/s^2**

Simulation results:

The results for the structural analysis are as shown (**Fig.12 to Fig.15**)

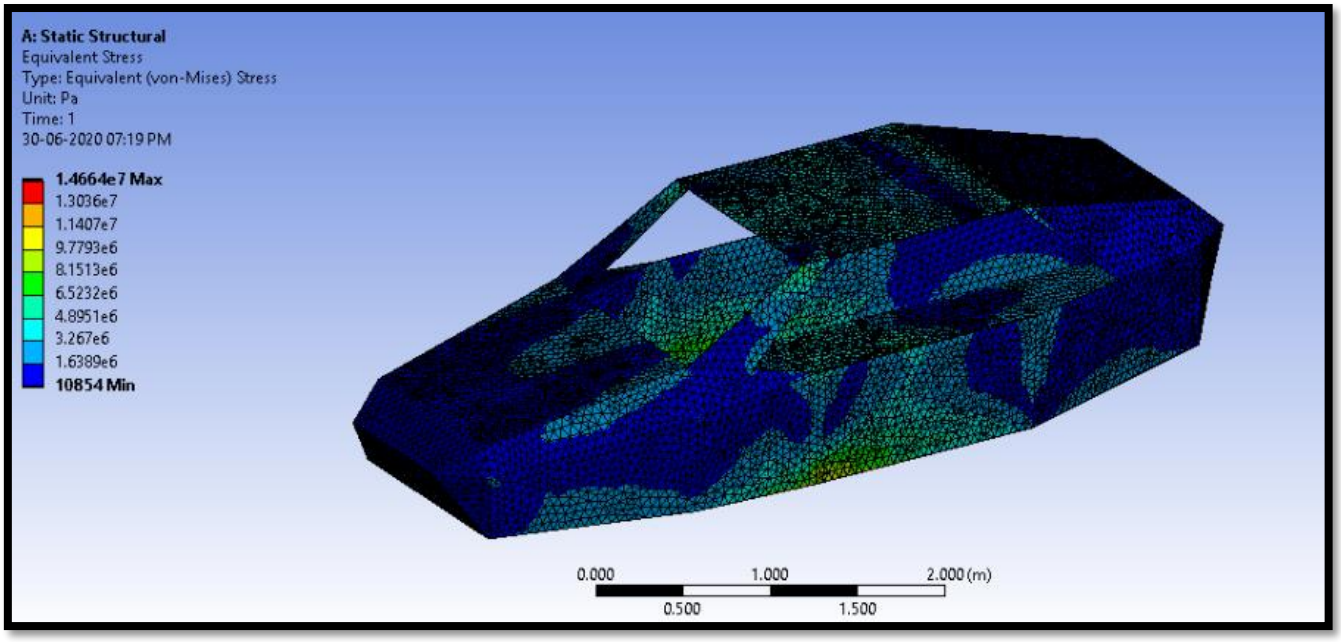

Fig 12: Equivalent stress analysis on vehicle body

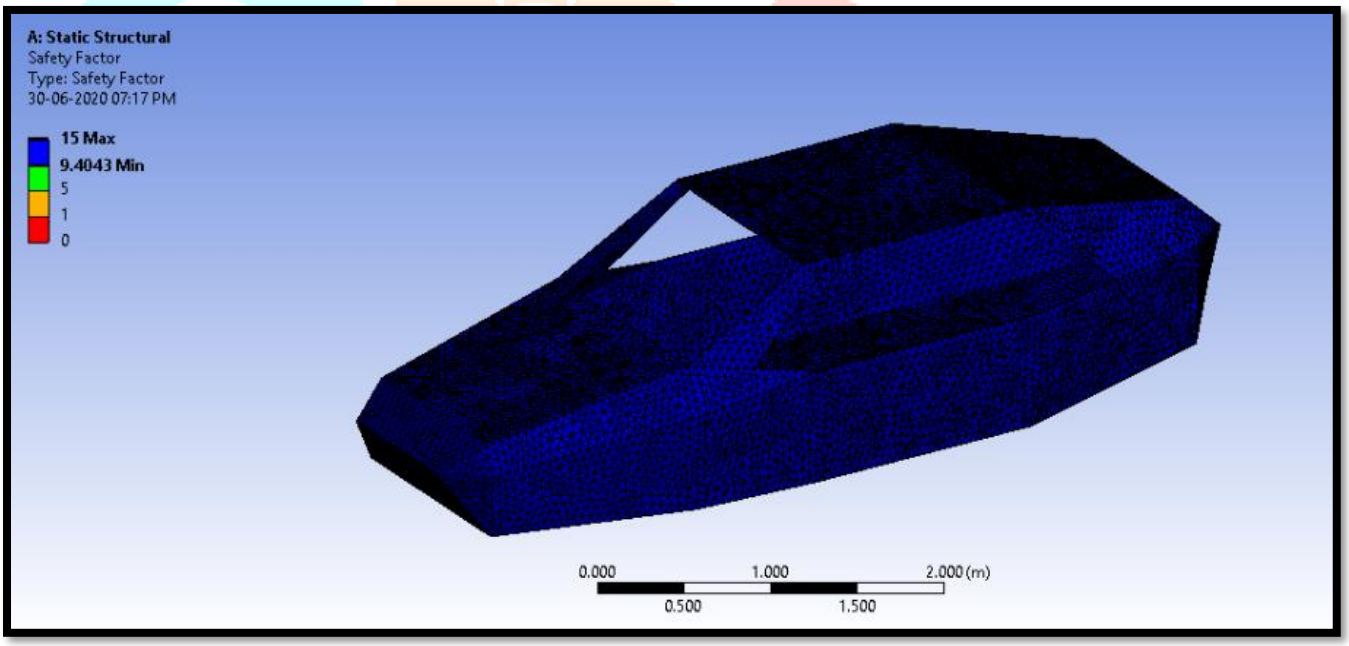

Fig 13: Factor of safety of vehicle

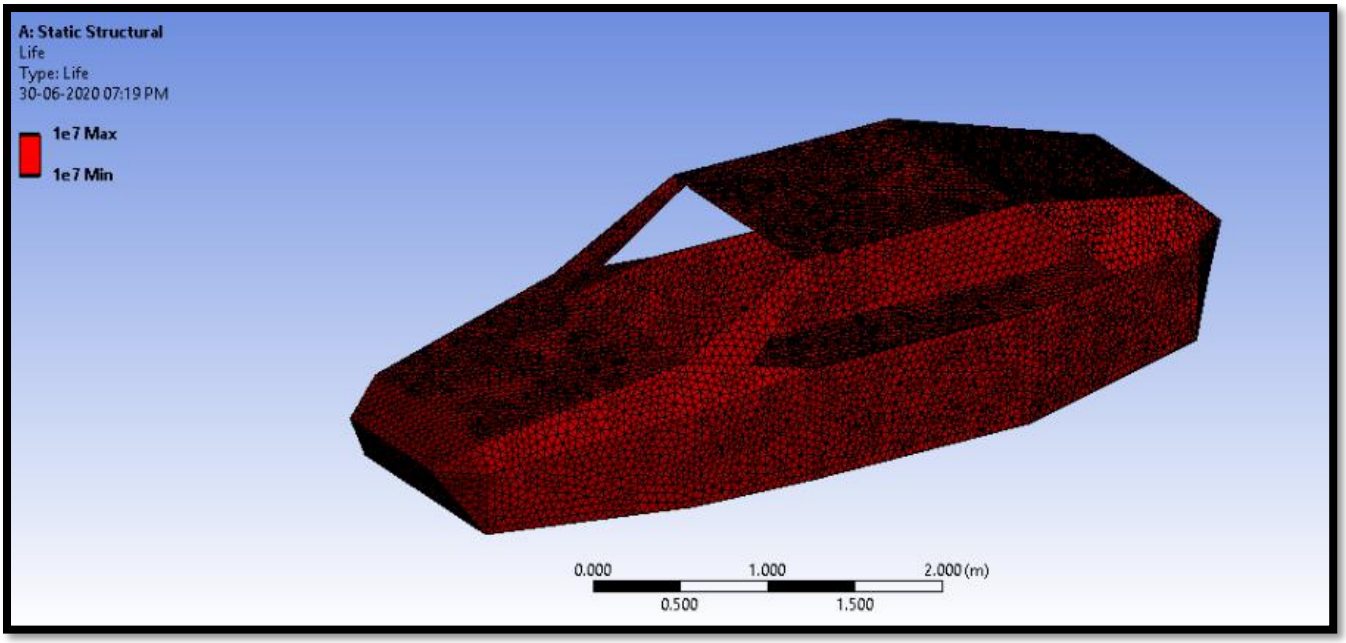

Fig 14: Fatigue analysis for life span

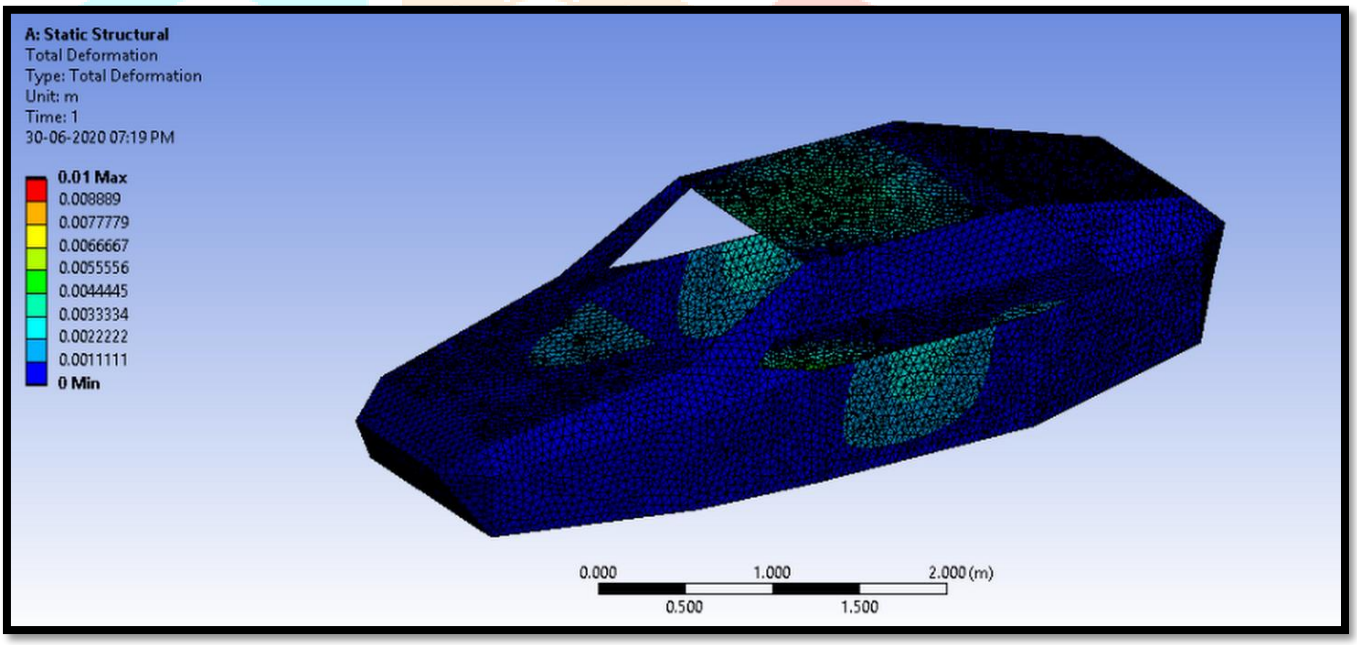

Fig 15: Deformation of vehicle body on impact

The data for the proposed vehicle is selected based on comparison with the body structure and aerodynamics with Honda Civic 2019.The following vehicles have been carefully studied in order to design the proposed vehicle:

- **Tesla Model S (Basic)** [10]
  - Motor = 362 hp (270 KW)→ (441 Nm)
  - Battery = 60 KWh
  - Top Speed = 220-250 kmph
- **Chevy Bolt EV**
  - Motor = 144 KW)→ (360 Nm)

- Battery = 60KWh
- Top Speed = 146 kmph

❖ **Tesla Model 3** [10]

- Motor = 346hp (258 kW) ----> (Dual Motor)
- Battery = 75 KWh (520 Nm Torque)
- Range = (180 – 280)Km (Indian City Estimate)
- Top Speed = 210 kmph

CONCLUSION:

According to the research conducted, the vehicle is designed to run on Indian Roads keeping in mind the restrictions imposed by the Regulatory bodies. Most of the electric vehicles in India have 100-120 km range and also the solar cars which are just entering the markets run for around 350km. As per the design and structural analysis of the designed vehicle, results imply that it is supposed to increase the range of a conventional electric vehicle by an additional 50km using solar energy.

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