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Design and Analysis of Solar Assisted Electrical Vehicle

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Abstract*: *Regular fuel-based vehicles are more reliable because of their rich looks, flexibility, influence, and preferred effectiveness over non-traditional electrical vehicles. Building a green vehicle is a test given the constraint in power transformation. The energy transfer rate of a sun-oriented power vehicle is less. In this proposition, this paper has endeavored to cover every one of the parameters and components influencing the manufacture of a sun-oriented controlled vehicle. Computer-aided engineering/design has played a significant job to accomplish the execution objectives of the vehicle. The present work visualize utilizing both sunlight based and electric forces to impel the vehicle since sun based power transformation is not enough to meet the complete power necessities. Considering weight, strength, and ergonomics an optimal chassis was designed. Then the chassis frame analyzed for different ride conditions. The suspension system and other vehicle systems were designed by following basic vehicle conditions and analyzed the components. Finally, the performance of the vehicle was estimated. According to those estimations, this vehicle is very much suitable for on-campus transport application. This design is just to give a brief idea to develop the solar-based electrically driven vehicles

Keywords* : *Solar vehicle, chassis design, non-conventional vehicles, electric car.

I. INTRODUCTION

Automobile industries are changing their path from conventional IC engine powered vehicles to environment-friendly alternative engines. Electrical motor-based vehicles are the best possible direction for them. However, the required energy for these electrical vehicles should not be from fossil fuel based engines, which gives pollution problem again. Converting renewable energy sources like sun, wind, tides, etc. into electrical energy is becoming the best alternative in all industries and home needs. Out of these sources, solar energy is the most sustainable source that will provide this energy forever. By using photovoltaic (PV) effect, this solar energy can be converted into electrical energy. Sunlight bombards the electrons, makes electrons move, and then these movements and interactions of electrons generate electrical current or energy that finally drives the car [1]

This PV technology is burgeoning with silicon-based solar panels, which are formed with an array of solar cells connecting series or parallel. Silicon is a semiconductor material, which absorbs sunlight and allows the PV effect.

Different types of solar panels like monocrystalline, polycrystalline, Thin-film solar cell etc.[2] were already introduced into commercial markets. Now a day foldable, flexible and smart solar panels are also available in the market. These flexible panels can be fitted on the solar car surface so that the vehicle can generate the required power directly from the Sun. A solar car is a vehicle which is powered by the sun`s energy through these panels, generally placed on the surface of the vehicle. A solar vehicle is an electric vehicle powered completely or partly by direct solar energy using photovoltaic cells contained in solar panels to convert the sun's energy directly into electric energy. These vehicles are not new; the first solar car materialized in 1955[3], World Solar Challenge (WSC) events since 1987 in Australia [4], and regular solar car challenge events were going in America [5].At present, solar vehicles are not sold as practical day-to-day transportation devices but are primarily demonstration vehicles and engineering exercises by professors of universities, often sponsored by government agencies. There are many universities and colleges, which have succeeded in creating a solar vehicle. Many organizations conduct solar car races to motivate people to design and manufacture solar powered vehicles. In this paper, the elementary procedure and design guidelines were included to give a brief idea to the reader in solar car designing aspects. To understand the solar car development procedure a simple case study is considered as shown in Fig.1

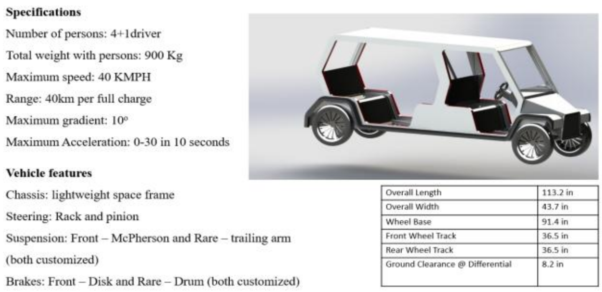

Fig. 1: The solar –electric hybrid powered car prototype with specifications

II. DESIGN PROCEDURE AND RESULTS

A. Chassis

The chassis frame is a significant part in the plan of any kind vehicle. Along these lines, the initial phase in this investigation is the design of the frame.

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Unbending nature and exemplary measurements for extravagance seating and legroom place are considered in the structure of casing.

Normally, the structure for these vehicles is a ladder frame outline yet that is excessively weighty and cannot take torsion loads.

To beat those issues space frame body is chosen for this structure, which is less in weight, handles even torsion stacks great and is cheap to fabricate, due to its less weight the working cycle per one-battery charges of the vehicle increments.

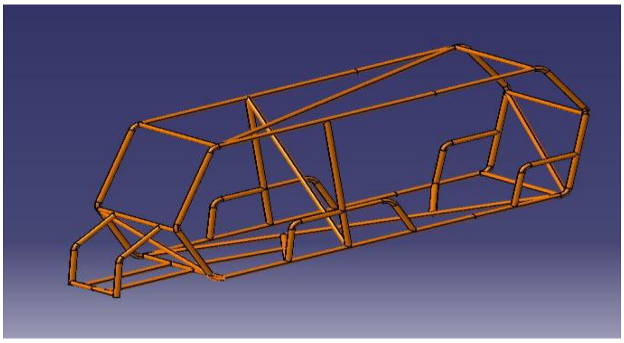


Fig. 2: Design of the chassis frame

Fig.2 shows the design of a chassis frame. In this design hollow pipe sections have selected which are regularly available in market. Material and the dimensions of the pipe is decided (AISI 1045 cold roll steel, 33mm diameter pipe with 2.5mm thick) by using computer-aided engineering tools while testing the frame in simulation. The cross members in the chassis are triangulations or bracings that provide the transfer of force easily and increase the rigidity rapidly, deign members should weld together by TIG (tungsten inert gas welding) for maximum strength.

Finite element analysis and optimization was done in CAE software's using a 1D mesh element. The purpose of finite element study was to the confirm passable factor of safety under various static and dynamic loading and to eliminate the chances of resonance occurrence. After calculating the G force, it was multiplied with the factor of safety to compensate for the unpredictable nature of loading. At a velocity of 40km/hr and 1G force, the front and side impact forces and developed stresses are as shown in table 1 and Fig. 3. Then the other safety tests also performed for the vehicle frame. Fig. 4 shows the stress developed during front bump and rollover conditions. This simulation study was helped in the development of rigid and lightweight frame.

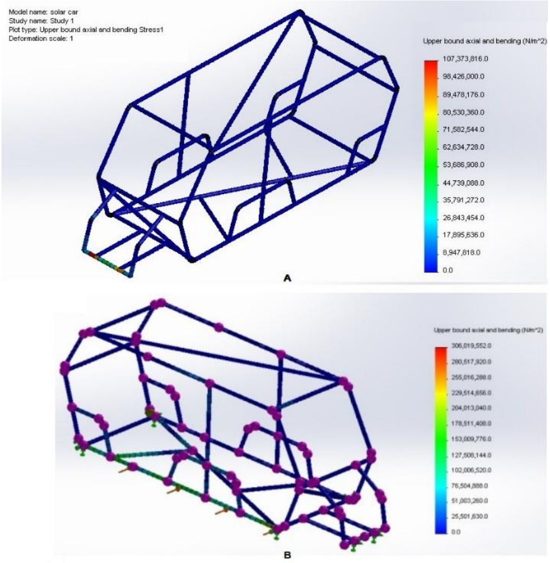


Fig. 3: Picture showing stress developed in roll cage during a) front impact b) side impact.

Table 1: Stress developed during front bump and rollover.

Condition	Stress (N/m^2)	F.O.S
Front impact	1.07374e+008	3.3
Side impact	3.0602e+008	1.1
Front bump	1.24481e+009	2.1
Roll over	1.000 e+009	1.5

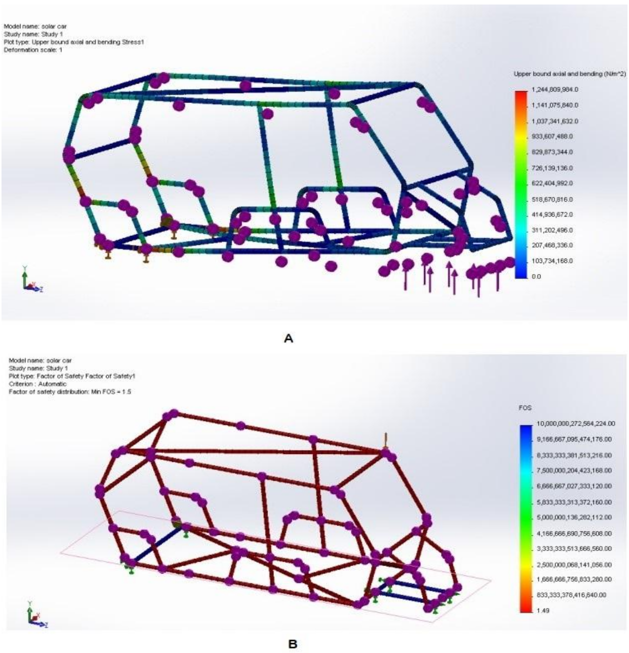


Fig. 4: Picture showing stress developed in roll cage during a) front bump b) roll over.

The torsional stiffness of chassis is related to aid understand how roll stiffness torques from the front and rear axles interrelate through the chassis. Changing the roll stiffness distribution between axles is a very common way to modify the balance of a vehicle.

If the chassis is too weak, the torsional stiffness is too low; any difference in roll stiffness between front and rear will be absorbed as twisting of the chassis.
Torsional rigidity calculation was carried out on 3G loading.
Result:
Maximum Stress: 74.41 Mpa.
Maximum Deformation: 10.37 mm.
Calculated torsional rigidity: 1787.28 Nm/deg.
Normal modal analysis was carried on from 1Hz to 100 Hz of external excitation frequency. The objective of modal analysis was to ensure that the natural frequency of roll cage doesn't match with frequency of motor in working range i.e. from 0 rpm to 4000 rpm and also determine that whether the mounting locations of components are suitable or not. It is important to know these frequencies because if cyclic loads are applied at these frequencies, the structure can go into a resonance condition that will lead to catastrophic failure.

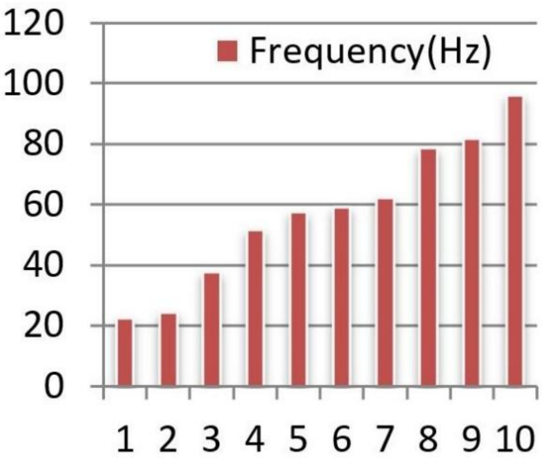
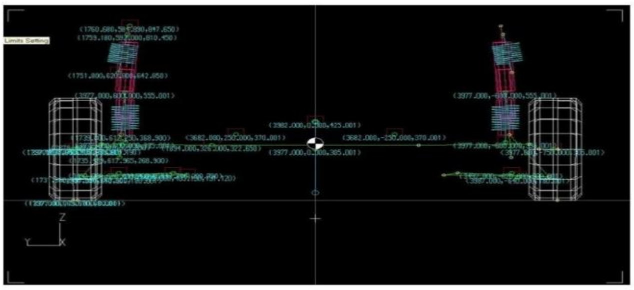


Fig. 5: Graph depicting Eigen value

It can be concluded from the results in Fig.5 that none of the Eigen value of the roll cage is matching with the external excitation frequency provided by the motor hence there will be no resonance.

B. Suspension

The requirement of suspension geometry is to have enhanced handling ability with a sheer ride in order to have a competing performance at the weakened race. Suspension Design includes Macpherson strut geometry at the front and 4-link rigid axle geometry at the rear. The roll stiffness of suspension should not exceed the torsional stiffness of chassis in any case during bump and jounce travel of the vehicle. Lotus Shark V4.1 was used to calculate the static and dynamic behavior of the vehicle. The geometry was modified to achieve the performance goal of our vehicle. Fig. 6 shows the finalized geometry values and running condition.



Parameter	Front	Rear
1. Camber Angle (deg)	0	0
2. Toe Angle (deg)	0	0
3. Toe Angle (Plane of Wheel)	0	0
4. Castor Angle(deg)	8.67	-
.5. Castor Trail(mm)	-5.23	-
6. Castor Offset(mm)	53.27	-
7. King Pin Offset at wheel(deg)	77.51	-
8. King Pin Offset (At Ground)(mm0	55.46	-
9. Mechanical Trail(mm)	52.66	-
10. Roll Centre Height (mm)	284.69	115.87

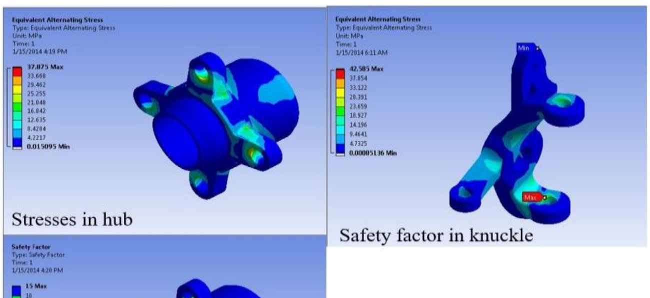
Run details

Parameter	Front	Rear
1. Bump Travel (mm)	127 ± 20	127
1. Rebound Travel(mm)	100 ± 20	100
1. Roll Angle(deg)	3	3
1. Steering Travel(mm)	30 ± 5	30

Fig. 6: Suspension geometry and run details

C. Suspension components

Depending on the scatter of material properties, geometrical shapes, and loading conditions, the fatigue life of mechanical components has a wide range of scattering although they were tested under the same conditions. An on-road vehicle comes under various loading conditions simultaneously. Therefore, for the better performance of the vehicle, its subcomponents should be robust. To ensure that vehicle performance goal is achieved, its various suspension components were designed for high fatigue life. CAE was used for the purpose of fatigue analysis. Mean stress theory used was the Goodman line. Loading condition that was taken under consideration was 1000Nm of braking torque, 1G lateral force, and 3G bump force. Fig. 7 shows the stress and factor of safety in the hub and knuckle for the applied braking torque. According to the simulation results, the components are having enough strength.



Component	Stress (Mpa)	Life (cycles)	Safety Factor
Knuckle	42.58	10^6	2.024
Hub	37.875	10^6	2.2759

Fig. 7: Simulation results for suspension components

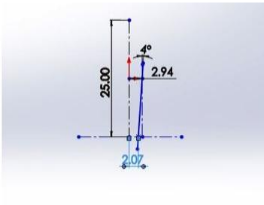
D.Steering System

The objective of the steering system is to control lateral motion while the vehicle is in longitudinal motion. The objective of the steering geometry was to provide Ackerman geometry. This geometry ensures that all wheels roll freely without slip because the wheels are steered to track a common turn center. Our target was to improve the sharpness of steering geometry and reduce unwanted disturbances from the track. We have selected a rack and pinion mechanism for ease of turning and better stability.

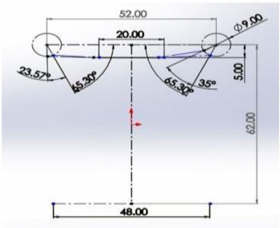
Steering Track Rod

Results

Parameters	Values
Track Rod length (in)	20
Tie Rod length (in)	15
Rack Travel (in)	1.77
Inner steer angle (degrees)	35
Outer steer angle (degrees)	23.57
Ackermann (%)	99.97
Turning Radius (m)	2.83
Steering Ratio	3:1
C factor (mm/degrees)	0.1994
Steering Effort (n-m)	125.1 Cas
Static Caster angle (degrees)	3
Static Camber angle (degrees)	0
King Pin inclination (degrees)	4
Scrub Radius (in)	2.07



Scrub radius calculation



Steering Geometry

Fig. 8: Scrub radius, Steering Geometry, and calculation results.

E.Braking

The brakes are one of the most important safety systems on the vehicle. The car uses disc & Drum brakes, Disc on each front and drum on rear wheel, to bring the vehicle to a quick and safe stop regardless of weather conditions or topography. Brake force required is calculated for the vehicle by considering mass to 1000 kg with the help of brake performance triangle. The braking torque is calculated of the vehicle, which provided the disc diameter for front and rear. It has been suggested to use caliper, which can give required braking force to fulfill the requirement.

F.Vehicle dynamics

Before the powertrain design stage, elementary information in vehicle longitudinal dynamics is important since it exposes what loads that the powertrain wants to manage with through driving. Rolling resistance, aerodynamic drag, grade resistance, and acceleration force are the major forces need to consider in this dynamic study[6].

Firstly, rolling resistance force (Fr): It is the force necessary to propel a vehicle over a particular surface.

$$F_r = C_r * m * g * \cos(\Theta), \qquad (1)$$

Next is, aerodynamic drag force (F_a): It is a drag force from the air during vehicle running.

$$F_a = \frac{1}{2} * C_d * \rho * A * (V_C - V_w)^2, \qquad (2)$$

Thirdly, grade resistance force (F_g): It is the amount of force necessary to move a vehicle up a slope or "grade". This calculation must be made using the maximum angle or grade the vehicle will be expected to climb in normal operation.

$$F_g = m * g * \sin(\Theta). \qquad (3)$$

Lastly, acceleration force(F_{acc}): It is the force necessary to accelerate from a stop to maximum speed in a desired time.

$$F_{acc} = m * a, \qquad (4)$$

To select motors capable of generating enough torque to drive the vehicle, it is required to determine the total tractive effort (FT) requirement for the vehicle:

$$F_T = F_r + F_g + F_a + F_{acc} \qquad (5)$$

This total force should be less than the maximum traction force available at wheel,

$$F_{traction} = \mu * m * g, \qquad (6)$$

where μ is friction coefficient at wheel. Finally, required torque at wheel is

$$T_w = F_T * R, \qquad (7)$$

where R is radius of the wheel. Wheel speed in rpm (N) $=V_C/(60 * 2 * \pi * R)$ (8)

After this dynamics calculations, propulsion motor and Energy storages must be designed to achieve above torque and speed.

G.Power unit

According to design requirements and safety regulation, BLDC series motor was selected. In addition, it is a combination of motor and transmission system in the axle, which is available in the market. Fig. 9 shows the image and some important specification of motor and transmission system

Model	BLDC
Torque	100 Nm
Power	3KW
Voltage	48V
Current	70A

.

Fig. 9: Motor &transmission system

Capacity of battery
Capacity of the battery depends on the range of the vehicle.
P_Battery = WHPM*Range,
where WHPM =Voltage*Current/mile per hour. Battery should have allowance i.e. 80% of the charge can only be used [7]. Therefore final battery capacity is 1.2 times of above capacity. Ampere-hour of battery,
AH= Ampere hour per mile * range* 1.2,
where Ampere-hour per mile = WHPM/Voltage.
Battery specifications for this design is as follows
Battery: Lithium ion Battery
Power: 4KW
Specs: 48V, 85A
Range: 40km

Li-ion (Lithium Iron Phosphate) batteries are the best possible batteries for this type of vehicles because of maintenance free, and low weight. Panasonic NCR 18650 cell is presently available Li-ion cell, which has a nominal voltage of 3.7V, AH is 3200mAH, and energy density of 243 Wh/kg [8]. By connecting a number of cells in series and parallel the require battery configuration can be achieved. If the Cells are connected in parallel, AH multiplies and voltage is constant. Same way, if they connect in series, voltage multiplies and current is constant [9]. For this vehicle, four 12V and 86AH modules are connected in series. Each module has twenty-six cells, which are linked in parallel. AC Level 1 charging and DC level 1 charging at stations are the options for this vehicle [10].

Final step in this design is solar panels selection for the car. In this model, solar power is an auxiliary power system, so total power for vehicle charging is a combination of solar power and electrical supply at the station. The station electric supply of 230v reduced with a step-down transformer to 48v. Total place available on the rooftop of the car is 1.09m*2.8m. Monocrystalline solar panels have chosen for this project, as they are space efficient and long life span. One 12v 100Wcapacity panel area is 1m*0.65m, therefore 4 panels can be fitted on the car rooftop as shown in Fig.10.

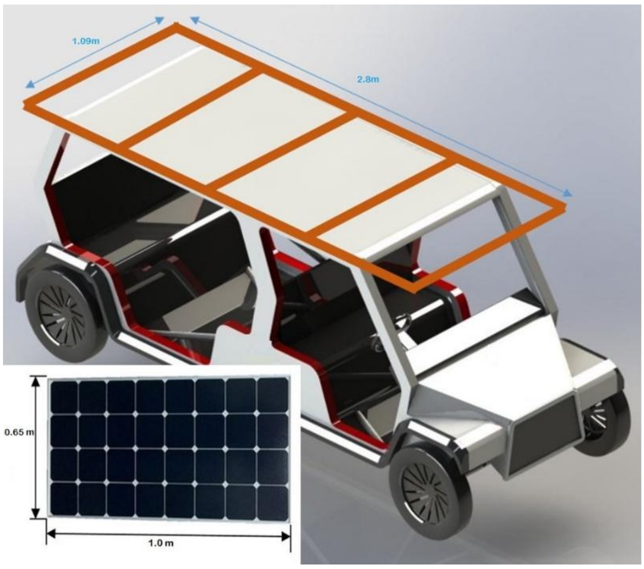


Fig. 10: Car rooftop fitted with 4 solar panels

The solar panels supply E= 4*100W* 6Hrs = 2400W = 2.4 KW/day. After considering the efficiency and losses of the panel E= 1.5 KWh/day. The solar panels provided can charge the entire battery system in 15 to 17 hours, i.e. three days light can charge the battery fully. In other words, on a clear sunny day, the solar panels can give 25% of its required propulsion power.

III. CONCLUSION

This paper discussed the basic steps needed to consider for the development of solar assisted electrical vehicles. Firstly, with the vehicle configuration requirements and automobiles standards, the chassis was designed. Then the vehicle sub systems like steering, suspension, and brakes were designed. According to the vehicle longitudinal dynamics requirement, the power train was chosen. For expected vehicle range power storage unit was estimated. Finally, solar panels were assigned to the available roof top space. Considered vehicle design in this paper is for on-campus application with a maximum speed of 40 km/h and 40 km/charge. Both solar and electric powers were considered to propel this car since solar power is inefficient to meet the total power requirements.

ACRONYMS AND NOMENCLATURE

m Vehicle mass (kg)
g Acceleration due to gravity (m/s^2)
C_r Surface friction coefficient
F_r Rolling resistance force
F_a Aerodynamic drag force
A_V Area of vehicle (m^2)
ρ Density of air (kg/m^3)
Vc Speed of the vehicle (m/s)
V_w Wind velocity (m/s)
C_d Drag coefficient
F_g Grade resistance force
F_T Total tractive effort
μ Friction coefficient at wheel
R Radius of the wheel (mm)
N Wheel speed in (rpm)
Θ Road grade.

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