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Development of an Indigenous Solar Powered Car

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Abstract— Cars running on fossil fuel do not only contribute to global warming and pollution, but they also have high running and maintenance cost, due to these challenges, the project seeks to alleviate these problems by adopting the a cost effective use of alternative renewable source of energy for land transportation. This work is on the development of an indigenous solar powered car. It involves the design and fabrication of a solar powered car from refurbished car components and with a carrying capacity of two people and a maximum speed of 30 km/hr. The car will runs entirely on a stand-alone integrated solar system, and designed with dimensions of 3 meters' x 1.6 meters. The maximum load carrying capacity of the vehicle is 700 kg and it requires a driving force of about 4.3 kW. The solar car uses a clean engine (available) made up of direct current brushed motor rated at 13 kW output power and sourcing its required power from the stand-alone solar system.

NB: The major calculations presented on this paper only reveal the power requirements of the designed Car.

Index Terms— Electro-chemical Batteries, Solar Car, DC Motor, Energy, PV, Renewable energy, Solar.

1 INTRODUCTION

The human population is ever increasing with projections from the United Nations estimating an additional 2.6 billion people to the planet by 2050.[1] This statistic indicates a greater demand on our already depleting conventional energy reserves. The automotive industry is one of the largest dependents on the conventional energy source in most developing countries, like Nigeria.[2] Most of its technologies are built to run on fossil fuels which is unsustainable and hazardous to the environment. The considerable risk it poses to society has necessitated the automotive industries to also seek for alternatives, thus probing researches into renewable energy technology. Solar energy is based on the radiation from the sun.[3] Innovations like, photovoltaic cells, solar heating and solar thermal have made feasible the capturing of energy from the sun and converting it into electricity and/or heat[3,5]. These systems are usually referred to either active or passive technology depending upon the capturing and circulation mode. Active technology includes the utilization of photovoltaic cells, being the most favored amongst other technology because of its competitive LCOE. Revealing this utilization of solar energy and numerous different applications, Tarik, Srea, Monzurul, and Khairul in 2012 stated that, PV generation (a dynamic system of harnessing the sun's energy) turn out to be twofold at regular intervals, expanding by a normal of 48 percent every year since 2002.[4] Solar energy has been the most effective source for fuelling electric vehicles in contrast with other renewable energy source.[5] This energy is harnessed and utilized specifically in form of electrical energy to power car. Md and Md in 2012 described a solar powered car as a type of electric car controlled by this sun based power.[6] The energy is acquired from PV cells often situated at the rooftop or surface of the car. Solar powered cars comprise solar panel, charge controller, battery and engine (electric motor).[6,12,15,17,20] Dissimilar to fossil fuelled cars, their engine has no emission and can either be Alternating current (AC) or Direct current (DC) engine.[6,10,12,17] Solar powered cars are yet to be commercialized on a broad scale. Nations like Germany, US, China and India are working towards its full commercialization.[7] Presently, they are fundamentally utilized as sport cars and for practical demonstrations or exhibitions.

The transformation of the sun's rays to power is done solely by the photovoltaic cells, which are made of semiconducting materials (e.g. Silicon).[8-9,19] Silicon is refined, handled and encased in a treated glass for security purposes.[9,16-17] The application of PV technology in the automotive industry has greatly contributed to the recent feat achieved in green technology.[10] As more effort will be channeled to reducing the severe hazards accompanying Greenhouse emissions, research in this area will not cease.[13-14] Nigeria has taken a foothold in this participation, increasing its efforts to develop a model of transportation utilizing renewable energy. The advent of solar cars has not only provided the automobile industry with clean energy, but an efficient and cost-effective technology.[20] This project focus on building one, using locally available components and materials.

NOMENCLATURE

E	Energy required from the solar panels (KWh)
F_a	Acceleration Force (N)
m	Mass (kg)
t	Time(s)
a	Acceleration (ms^{-2})
V	Initial Velocity (ms^{-1})
U	Final Velocity (ms^{-1})
F_r	Rolling Resistance (N)
W	Weight
C_r	Coefficient of Rolling Resistance
F_d	Drag Force (N)
C_d	Coefficient of Drag
A	Frontal Area (m^2)
ρ	Density (Kg/m^3)
$\emptyset$	Inclination
P	Gradability
F_g	Gradient Force (N)
T	Starting Torque (Nm)
r	Solar panel yield (%)
H	Annual Average Solar Radiation on tilted panel
g	acceleration due to gravity
PR	Performance ratio or coefficient for loses

2 Objective

The aim of this paper is to design and develop a prototype solar powered car which will be clean, reliable, economical and environmentally friendly. The car is design to scale with dimensions of around 3 meters' in length x 1.6 meters' in width and would only carry two people alongside its accessories which include electro-chemical batteries, DC motor, charge controllers and PV array. It uses a battery pack of 48 V and 150 Ah, and a motor controller to vary the speed. The batteries receive charges from 3 PV modules each of 180 W (total of 540 W). The chassis of the car is fabricated using local content materials to cut expenses and easily control the weight.

3 Component Description

The structure of the solar car is sectioned into chassis and body, transmission and steering system, suspension system, wheels (all considered as the mechanical components, made up of about 60 % local content) and the electrical/solar components.

3.1 Chassis and Body

Chassis is the backbone of the vehicle since all the mechanism of the solar car like the transmission system, axle, wheels and tyres, suspension and also the control systems and electrical components are mounted on the chassis frame, including the body. The different types of chassis; ladder, space frame, monocoque and backbone chassis used in automobile were considered before picking the one that suits our design considerations using the solar car designs and assumptions in perspective chassis. The space frame chassis is suitable to the specifications and materials to be used. The space frame chassis utilizes dozens of circular-section tubes and square-section tubes positioned in different directions to give mechanical strength against forces from every direction. The tubes are welded together to form a very complex structure with maximum strength in all directions. In designing the chassis, it was necessary to carry out some numerical analysis for the forces and stresses acting on the chassis.

3.2 Transmission System

Solar vehicles do not require the Orthodox transmission system with several speeds.[4,19] The polarity of the electric motor is essentially reversed when the vehicle needs to be reversed. This implies the direction of rotation of the electric motor and this is done using a gear selector lever, which simply has the positions; Neutral, Forward and Reverse and the speed can be regulated with the accelerator pedal. Based on the design specification, the rare axle differential is connected to the rare wheel from the electric motor positioned centrally in the chassis to relay and convert the rotational motion to linear motion thus enabling the car to move forward.

3.3 Suspension System

This system is a major automobile subsystem which is a mechanical assembly that connects each wheel to the body. Basically, the suspension system functions as to isolate the body of the car from the vertical motion of the wheels as it travel over tough road surface, since the wheel assembly is connected through a movable assembly to the body. Suspension system in solar vehicles consists of the wheel assembly, the spring which support the weight of the car. In addition, a shock absorber (sometimes a strut) which is in effect a viscous damping device. Solar cars have a very stiff suspension designed to prevent damage to the frame in the event of large jolts. For the front wheels, almost all solar cars utilize double A-arm system and it is completely an independent suspension. It is a compact system that lowers the vehicle hood resulting in greater visibility and better aerodynamics.

3.4 Steering System

This system is one of the major subsystems required for operation of the car. It provides the driver control over the car as it traces a path along the ground.
It consists solely of a mechanical means for rotating the wheels

about a nominally vertical axis in respond to the rotation of the

steering wheel. The rack and pinion steering system is considered for this application. It uses the steering column, steering wheels and steering shaft to transfer the drivers turning effort to gears in the steering gear assembly.

3.5 Electrical/Solar Components

This constitutes the solar array, power train and the telemetry. The power train comprises of the high voltage system (solar array, battery pack and motor) and low voltage systems (sensors, motor controller, lights and drive controller). The low voltage systems are carefully designed following standard electrical and power circuits.

The basic numerical analysis to show energy requirements from the electrical components are reported below.

$E = A \times r \times H \times PR$

$r = \frac{Electric\ power(KW_P)\ of\ one\ solar\ panel}{Area\ of\ one\ panel}$

Electric Power of One Solar Panel $= 0.18\ KW_p$

$PR = 0.75$

$A = 1.2766\ m^2$

$H = 231.69g\ W/m^2$

$$r = \frac{180}{1.2766} = 1.41\%$$

$E = 1.2766 \times 1.41 \times 231.69 \times 0.75 = 312.78KWh$

To calculate the charge it can supply to the battery in 8hrs;

Solar Panel Wattage= 540 W

Factor of natural system losses= 0.85

$\therefore\ Charge\ supplied = 540 \times 8 \times 0.85 = 3672\ Wh$

Battery Capacity

$Amount\ of\ power\ battery\ can\ supply = AH \times Battery\ voltage$

$AH = Charge\ storage\ capacity\ of\ battery$

$AH = 150\ Ah$

$Battery\ voltage = 48\ V$

$Amount\ of\ Energy\ supplied = 150 \times 48 = 7200WH\ or\ 7.2\ KWH$

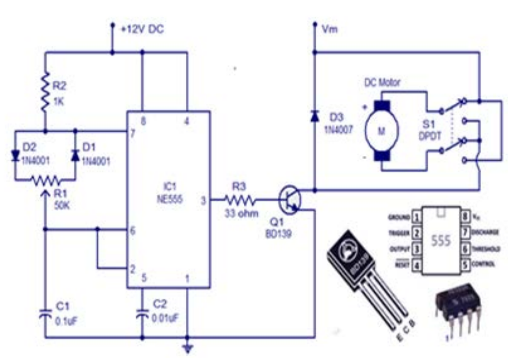

Fig 1: Electrical circuit for the motor controller

4 Working Principle

The vehicle is a solar powered car. It runs on electrical energy which is obtained from the transformation of solar radiation into electrical energy. The simple working principle of the car involves; energy being harnessed from the sun via solar panels (PV arrays) and used to charge a battery bank which stores this energy in form of electrical charges. The battery pack supplies this energy to an electric motor which is connected to the vehicle wheels by means of the transmission system (in this case a rear axle differential assembly).

5 Vehicle Calculation

5.1 Basic Assumptions Made/Vehicle Specifications

1. Gross weight of the vehicle including two (2) passengers: 700 kg
2. Maximum Velocity to be Achieved: $30km/hr$ (8.33 m/s)
3. Wheel Diameter: 15" (0.381 m)
4. Maximum Gradient Climb: 5°
5. Surface Friction Factor: 0.03 (Coefficient of friction between wheel and road)
6. Time Taken to achieve Maximum Speed: 30 seconds
7. Sprung Weight: 700 kg
8. Spring Length Closed(mm): 190
   Spring Rate/Stiffness (kN/m): 310.7(rear) and 18.47(front)
9. Coefficient of drag: 0.674 (possible value from the aerodynamic shape of the car)

5.2 Vehicle Rating

Force to Achieve Speed and Acceleration

$F_a = ma$

$Mass = 700kg$

$t = 30seconds$

$a = \frac{V-U}{t}$

$$= \frac{8.33-0}{30} = 0.28m/s^2$$

$\therefore F_a = 700 \times 0.28$

$= 194.37\ N$

Force to overcome rolling resistance

$F_r = WC_r$

$W = 700 \times 9.81$

$= 6867N$

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$C_r = 0.03$

$\therefore F_r = 6867 \times 0.03$

$= 206.01N$

Aerodynamic Drag Force

$F_d = \frac{1}{2}(\rho C_d A V^2)$
$F_d = \frac{1}{2} \times 1.225 \times 0.674 \times 1.12 \times 8.33^2$

$= 32.08\ N$

Gradient Force

$\emptyset = \tan^{-1} C_r$
$= \tan^{-1} 0.03 = 1.7184°$

$P = W \tan(\theta + \emptyset)$

$= 700 \tan(5 + 1.7184)$

$= 700 \times 0.1178$

$= 82.46\ N$

$F_g = P \cos\theta$

$= 82.46 \cos 5 = 82.15\ N$

Total Force required by the Vehicle

$F_a + F_d + F_r + F_g = 194.37 + 206.01 + 32.08 + 82.15$

$= 514.61\ N$

Required Drive Torque/Tractive Torque

$T = F_a \times r$
$r = 0.1905\ m$
$F_a = 194.37N$
$T = 194.37 \times 0.1905$
$= 37.03\ Nm$
Vehicle power required =
$Power = Force\ x\ Velocity$
514.01×8.33
$= 4286.70$
$= 4.3\ kW$

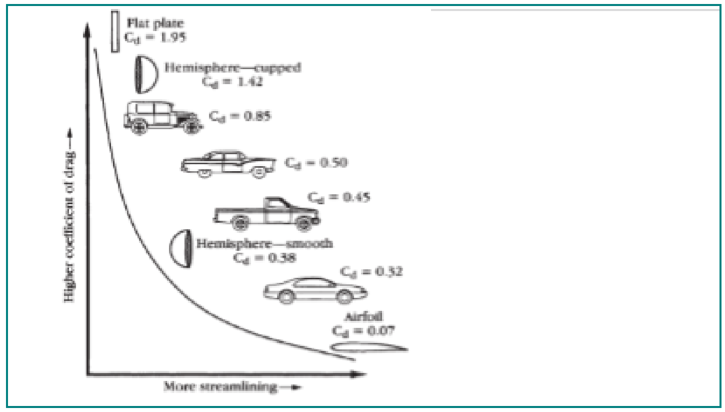


Fig 2: Coefficient of drag

5.3 Material Content and Cost

The main Idea behind the project initiation was to develop an indigenous solar powered car utilizing local content materials. The chassis components, car frame and body were sourced from refurbished or used automobile parts. This is to show that the car can be built entirely by fabricating the materials locally. Although the significant challenge is the resulting weight of this materials, thereby given a total weight a bit more than the conceptual design weight. An improved refurbishment technique will improve these local contents.

Table 1: Highlights of the material used in the chassis section.

S/N	Materials	Functions	Desired Properties	Candidate Material
	Chassis section			
1	Base frame	Hold and support the car body and power train.	Good tensile strength, tough	ASTM A29
2	Top frame	Base for panels	Compressive strength	AISI 1035
3	Suspension A-arm	Supports vehicle weight	High spring rate	AISI 1040
4	Pro-links	Vertical movement of axle	Good tensile strength	AISI 1035 Galvanized Steel
5	Foot plate	Base support	Good tensile strength	ASTM A1011

The material for the body section was choosing with the criteria that enable the driver and the passenger the needed comfort while in the car for safe driving. These also necessitate the choice of the material used for interior design.

Consequently the labour cost in building the car takes about 55 per cent of the total cost incurred. This is more than the 20 - 35 per cent of standard automobile manufacturing industry. The lower material cost and enormous refurbishing activities contributed to the huge percentage difference. More importantly, refurbishing used car components is one of the significant factors to be considered in the Life Cycle Assessment (LCA) in Automobile industry. This will help to lower the overall emissions of vehicle production and keep in check the materials used in car manufacturing.

Table 2: Overview of vehicle life cycle activities and estimated emissions

Vehicle life cycle	Activities	Possible level of emissions
Vehicle production	Material refurbishment, and vehicle assembly	Less emissions compare to extractions and productions of newer components
Vehicle operation	Distance covered during use	Energy uses emission free No emission from maintenance
End-of-life	Engine recycling (DC motor and batteries	Trace emissions

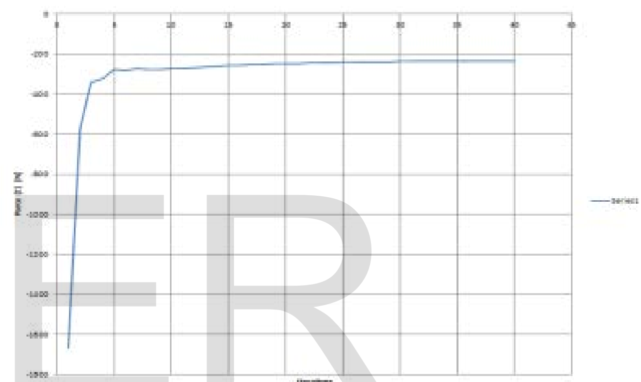
The case provided in the table above is based on rough estimation (rough measurement of carbon foot-print), and a deep LCA methodology has not been conducted to actually measure the actual amount of emissions of the entire process.

6 Results and Discussion

The simulations carried out on the car include Computational Fluid Dynamics (flow simulation), frame stress analysis, frame displacement analysis. This was done with the use of Solidworks software.

Table 3: Results Summary of Forces Acting Against the Frame for Computational Fluid Dynamic (Flow Simulation)

Value(N)	Average Value(N)	Minimum Value(N)	Maximum Value(N)	Delta(N)	Criteria (N)
-234.0410074	-238.3399807	-246.3935986	-233.9750293	12.4185693	16.08258443
				Analysis Interval=20 Iterations=40	



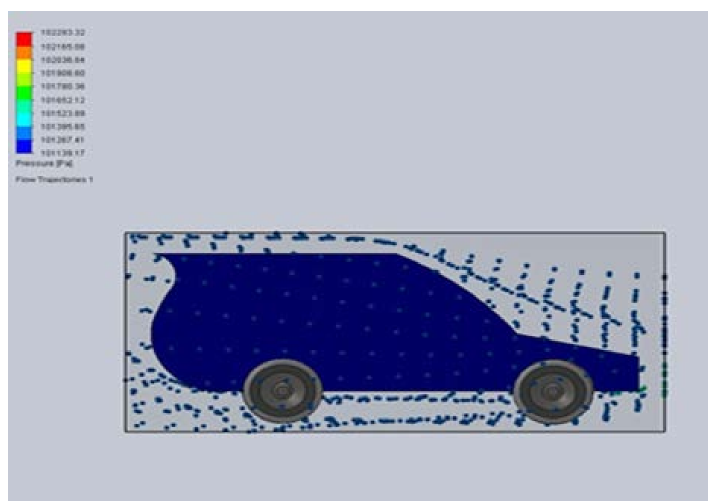


Fig 3: Graph Forces Acting on the Frame against Number of Simulation Iterations

Fig 4: Flow Trajectories One (1)

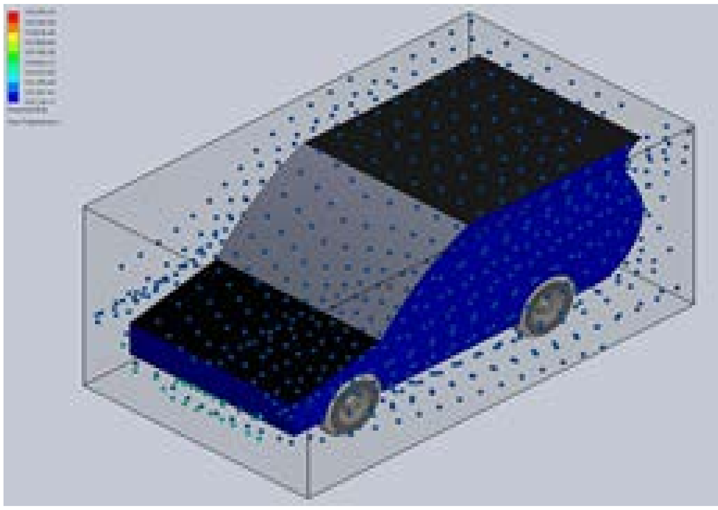
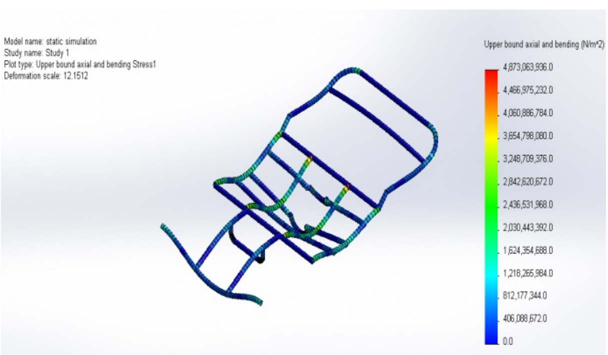


Fig 5: Flow Trajectories One (2)

TABLE 2
FRAME STRESS ANALYSIS

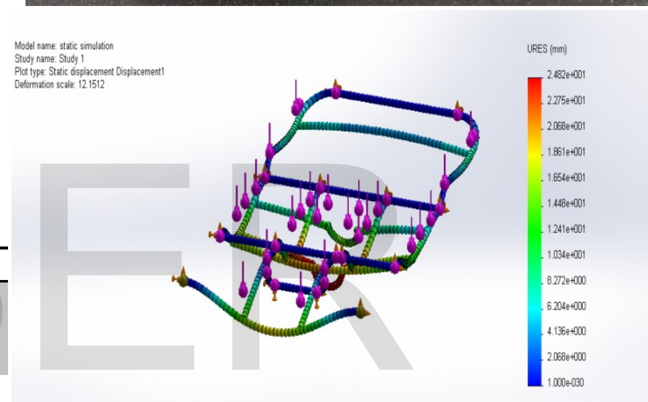
Name	Type	Min	Max
Stress1	TXY: Shear in Y Dir. on YZ Plane	0 N/m^2 Element: 107	4.87306e+009 N/m^2 Element: 535



static simulation-Study 1-Stress-Stress1

TABLE 3
FRAME DISPLACEMENT ANALYSIS

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 21	24.8161 mm Node: 179



static simulation-Study 1-Displacement-Displacement1

The results of the flow simulation (CFD), the total drag force obtained is 15 N, which is moderate and only noticeable at speeds above 30 km/hr. The displacement analysis (FEA) carried out on each critical element (members) of the frame/chassis reveals that the frame is stable and will perform efficiently at the specified conditions. During driving of the developed Solar Car, the Car was able to overcome the starting torque of 37.03 Nm. This justifies that the developed Solar Car passes the initial static road condition test.

Fig 6: The Developed Car

7 Conclusion

It is clear that the project was able to get acquainted with this new area of photovoltaic solar energy application. Components and equipment purchased for the development of the solar-powered car were and fully utilized in building and testing the car. The chassis/body and other mechanical parts where sourced, refurbished and locally built. An improved production activities will offers local car manufacturing companies a useful alternative in reducing their carbon emissions.

The following can be recommended for further work;

I. Continuous works especially on the electrical installations and control systems is necessary. Further testing to ascertain the efficiency of the car is also recommended.

II. In subsequent design of the solar-powered car, to reduce the weight and drag force, lighter material such as aluminium should be used in building the frame/chassis. A more efficient and lighter electric motor should be utilized. Accessories such as lighting systems, wipers, and charging outlets is an important area to look into, government and private companies should seek to build such charging stations.

III. Finally, solar technology is an alternative that can be commercialized to replace non-renewable energy sources. It is also very necessary to consider factors such as weather, environment factor, reliability of solar module and load to develop effective and efficient solar technology.

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