International Journal of Recent Engineering Research and Development (IJRERD)
ISSN: 2455-8761
www.ijrerd.com || Volume 03 – Issue 05 || May 2018 || PP. 133-141

Design of a Four-Wheeled Low-Cost Electric Solar Vehicle (ESV) in Bauchi State, Nigeria

Bala A.M[1], C. S. Onate [2], G.N. Jola[3], I.F. Ibrahim[4]

[(1, 2, 3 & 4)] Department of Electrical and Electronics Engineering Technology
Federal Polytechnic, Bauchi State, Nigeria

Abstract: An electric solar vehicle primarily harnesses energy from the sun via solar panels. A solar panel is a packaged, connected assembled of solar cells, also called photovoltaic which are solid state devices that can convert solar energy directly into electrical energy through quantum mechanical transitions. They are noiseless and pollution free with no rotation parts and need minimum maintenance. Photovoltaic cells (PVC) are installed on the vehicle to collect and covert solar energy into electric energy. Made of silicon and alloys of indium, gallium and nitrogen, the semiconductors absorbs light and then release it, producing a flow of electrons that generate electricity from 2 solar panels each with power rating of 100W which charges the 60v battery connected to it via a charge control which runs to ensure efficient storage of charge in a battery pack. The 1.5kW brushless DC motor was used to transmit power to drive the vehicle. The motor was designed to run directly by the power generated through solar cells. As the car is to run faster and with appreciable torque, the weight of the car was taken into consideration. The design is made such that the car has proper to weight ratio and is of less weight and has high strength which is the foremost requirement of any solar vehicle. The design of a motor controller to control the car's speed and forward/reverse direction of motion was also considered.
Keywords: Solar cells, Photovoltaic cells, Brushless d.c. motor, solid state devices, quantum Mechanical transition.

Introduction

The searching and study (quests) for a constant, safe, clean, cheaper and environmental friendly fuel cannot be over emphasized. Nowadays, dealers of natural resources like fuel, coal etc. are facing a hard time to keep pace with the increasing demand. At one hand, more cars or motor vehicles are dominating the transport medium, on the other hand, these car are being suppressed by the fuel. As a result, the limited resources are being suppressed by the producers and dealers to satisfy this need which is leading us to an uncertain future with having the scarcity of fuel and minerals [7]. This paper is mainly designed to build an electric solar powered vehicle that is likely to disrupt the carbon-based fuel cars that are unsustainable and hazardous to our environment and also to build up internet toward renewable energy source, mechatronics projects and enhance theoretical as well as practical knowledge along with management and team work of students.

The vehicle harness energy from the sun through a solar panel made from solar cells and also called photovoltaic cells. Photovoltaic systems make use of the photovoltaic effect (photo - light and voltaic - electricity), the basic process discovered the PV effects while experimenting with an electrolytic cell made up of the two metal electrodes, finding that certain materials would produce small amounts of electric current when exposed to light [3].

1.1 Need for Solar Energy at Present Situation

Earth has limited amount of energy resources which is very soon going to extinct. Fortunately population models here suggest that the world's population will probably level out at about two to three times the present numbers over the next hundred years. As the population is increasing the demands of people is also increasing. The question is whether the earth's resources are sufficient to sustain that population at a high standard of living for all in this key issue is energy.

Also, problems of global warming, environmental imbalance, and ozone layer depletion etc. which in turn is a big threat to the future human race. Again, in view of the possibility of global warming, these resources are playing a negative role. Therefore, under this circumstance, it is quite necessary to make a new exploration of natural resource of energy and power. But why exploration when the resource is in front of our bear eye. It is effective, less expensive and above all, it is an endless source of energy with greatly improved energy efficiency, a transition to the energy based economy capable of sustaining the anticipated growth in the world economy is possible. This effective source is solar energy.

Furthermore, the earth is suffering as a result of the destruction wreaked upon (caused a lot of damage) it by humanity. Whether it is the pesticides contaminants from vehicles and industries polluting the air, the systematic destruction of our different ecosystems all over the world have led to a dreadfulness our main focus is on the transportation industry which is the second largest source of pollution and health hazards. The electric power industry is the leading source of pollution.

Finally, fuel-based cars not only threaten the very air we breathe in but also the cost if running and maintaining them are huge and overbearing and as the fossil fuels are gradually being depleted, the cost of these limited sources resources, the existing fuels prices are continuously rising.

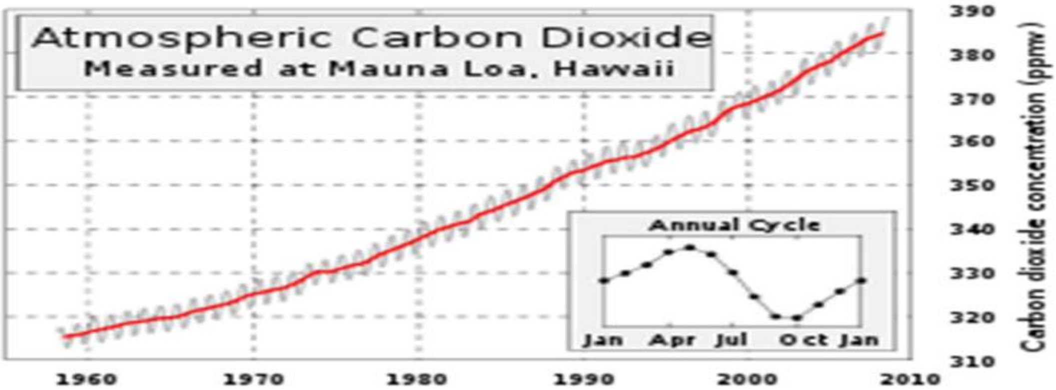

Fig. 1.1 World CO_2 Emission

1.2 Aim and Objectives of the Project

The aim and objectives of this project is to construct a four wheeled prototype powered car with a maximum weight of 500kg powered by a 1.5kW, 30v brushless d.c. motor that will pave away in the future to allow transport for people travelling a certain amount of distance every day, for instance, the office commuters of Bauchi state with virtually no cost as it will run off free renewable solar energy. Since cars are the major mode of transport for office commuters in Bauchi state, shifting to this eco-friendly car should later prove that this is easily possible. The prototype solar powered car to be designed and built specifically for the daily office goers of Bauchi state would be light-weight, clean, environmental friendly and completely independent of fossil fuels.

1.3 Project Overview

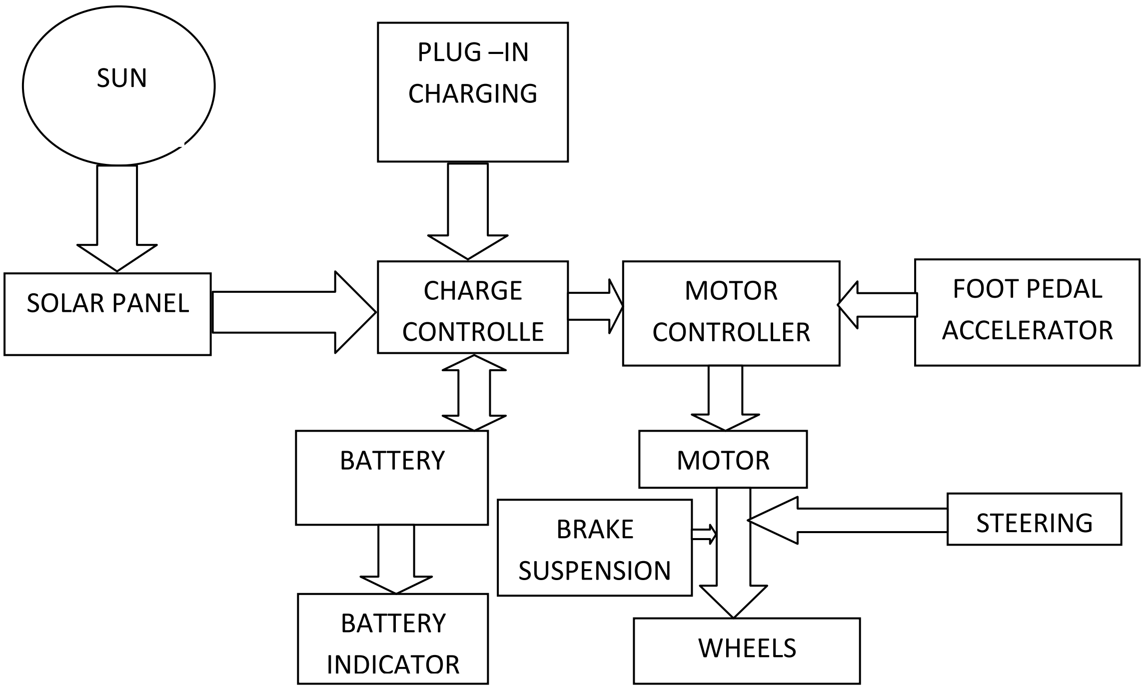

Figure 1.3 Block Diagram of Solar Powered Car

According to the system architecture of the solar car system in figure 1.3, the solar car system would consist of 11 main parts when the car stationary and connected to main supply. A 240v a.c. source provides supply to the battery charging system. While the solar panel absorbed energy from the sun and convert the solar energy into electrical energy, the electrical formed is being fed to the batteries that power the d.c motor through polarity switch and speed controller system. The polarity switch is made for forward and reverse direction of the d.c motor, while the speed controller adjusts the amount of energy that flows to the motor. As the power supplied to the d.c. motor, it rotates the propellers shaft connected to it.

1.4 Scope of the Project

The scope of the project is restricted to the solar radiation energy intensity available within the Nigeria atmosphere and other related locations where locations are in the tropics have a tropical hot climate that characterized sub-Sahara Africa and Nigeria which is rich in solar strength with average solar radiation energy of $7kWh/m^2$ per day i.e. 7 hours of $1000W/m^2$ per day. The specification of the motor driving the car is calculated based on the intensity desired speed and acceleration to be achieved. This will in turn help calculate the battery capacity and solar panel wattage required to travel the desired maximum round trip distance around Bauchi state metropolis.

A charge controller with the option is addition charging from AC lines and a motor controller to control the speedy and direction of motion of the car is designed. The chassis of the car is constructed with key components such as suspension system a rack and pinion steering system, drum braking system all put into place[4].

2.0 Literature Survey

It is necessary to understand solar energy collection and its conversion into electricity, evaluation of electricity performance and the current efforts being made to improve conversion efficiency.

The primary material used in the collection of solar energy is silicon. Even though it takes 100 times move surface area of silicon than that of other solid-state materials to collect the same amount of energy, silicon was already developed and in mass production when solar energy collection technology was developed and so it was the practical choice [7].

However, any semiconductor is acceptable. The semiconductor if part of a panel called a photovoltaic or solar cell. This cell absorbs sunlight and transfers into electricity, typically with a 15-20% efficiency [5].

2.1 History and Development of Solar Vehicle

In 1955, Willian G. Cobb of the General motors Corp. (GM) demonstrates his 15inch long "sun-mobile", world's first ever solar- powered automobile at the general motors powerama auto show held in Chicago, Illinois. Cobb's sun mobile introduced the field of photovoltaics the process by which the sun's rays are converted into electricity when exposed to certain surfaces. When converted hit 12 photoelectric cells made of selenium (a non-metal substance with conducting properties) built into the sun mobile, an electric current was produced which in turn powered on electric motor. The motor turned the vehicles drive shaft which was connected to its rear axle by a pulley.

In 1962, the first solar car that a person could drive was demonstrated to the public. The international rectifier company converter a vintage model 1912 baker electric car to run on photovoltaic energy in 1958, but they didn't show it until 4 years later. Around 10,640 individual solar cells were mounted to the roof top of the baker to help propel it.

At Tel Aviv University in Israel, Arye Braustein and his colleagues created a solar car in 1980. The solar car had a solar panel on the hood and on the roof. The critic car composed of 432 cells creating 400W of peak power. The solar car used 8 batteries of 6 volts each to store the photovoltaic energy. The 1320 pounds solar critical is said by the engineering department to have been able to reach up to 40mph with a maximum range of 50 miles.

In 1981, Greg Johnson and Joel Dandson invented the sun runner solar race car. The sun runner set the official Guinness world record in Bell flower, California of 24.7mph. In the majare Desert of California and final top speed of 41mph was officially recorded for a solely solar powered vehicle (did not use a battery). The 1986 Guinness book of world records publicized these official records.

2.2 What is Solar Energy

Solar energy is the energy provided by the sun. It is the radiant light and heat from the sun, harnessed using a range of ever-evolving technologist such as solar heating, solar photovoltaic, solar thermal electricity, solar architecture and artificial photosynthesis. Energy is produced in the sun by nuclear fusion during a series of steps called the proton-proton (P-P) chain, converting hydrogen to helium. This is the only part of the sun that produces an appreciable amount of heat through fusion about 99%. Hydrogen nuclei in sun's core fuse together to form helium nuclei and release energy, this process is called nuclear fusion.

The sun radiates energy equally in all directions and the earth intercepts and receives part of this energy. The power flux reaching the top of the earth's atmosphere is about 1400W/m^2. This measure simply means that on the average, one square meter on the side of the earth facing the sun receives energy from the sun equal to that from fourteen 100W light bulbs every second. The earth receives 173petawatt i.e. 173,000terawatt of incoming solar radiation (insulation) at the upper atmosphere. Approximately 30% is reflected back to the space while the rest is absorbed by the clouds, oceans and land masses.[6]

2.3 Solar Panel

Solar cars are powered by the sun's energy ergo therefore solar panels are the most important part of a solar car since they are solely responsible for collecting the sun's energy. The solar panels used in this project are mono crystalline mounted on top of the car.

2.1 Batteries

The solar panels will collect energy from the sun and convert it into usable electrical energy, which in turn will be stored in the lead acid batteries to be supplied to the motor when necessary.

2.5 Charge controller

The batteries are connected to a charge controller which will ensure healthy life of the batteries by preventing it from over charging and over discharging. A microcontroller inside the charge controller is programmed to detect the voltage at the battery terminal and/or the panel terminals accordingly determine what charging current the battery needs to be supplied.

2.6 Plug-In Charging

A critical factor here is that the charge controller will be available with an additional input that can be used to charge the batteries from A.C power supply (simply by plugging in). Thus the solar car will have this plug-in charging system for use when there is not enough sunshine due to fog, cloud or rain. This provision for an external plug-in system to charge the batteries from the conventional A.C Power supply will allow the car to increase its overall utility.

2.7 Motor and Motor Controller

The motor used is a D.C series excitation motor which is rated 1.5 kW, 36 V, this D.C. series motor is sufficient to get the car up and running as will be shown in details later. The motor controller is designed to control the speed of rotation of the motor as well as the direction of its rotation. In other words, it determines the cars speed and forward/reverse direction of motion of the wheels.

2.8 Steering suspension, brakes, wheels

These four components made up the mechanical part of the solar car. Front wheel steering is used as it tends to be more stable and safe.

The suspension used is sophisticated enough to allow the user a stable ride and to protect the car and panels from sudden shocks and blows.

A drum braking system as in conventional cars is used to provide the safety features of the car while travelling.

The wheel selection is dependent upon the rolling resistance which would determine how far the solar car can travel with the available energy. Since thicker wheels tend to have higher rolling resistance, thinner but strong wheels are opted for.

3.0 Design and Calculation

Solar cars compared to internal combustion engine vehicles are simpler in that they have few major components. The net weight of the vehicle is allowed to be 500kg. This would include the material component of the vehicle carriage load and the human load.

The system is powered by D.C motor connected to the battery bank. The battery bank is constantly charged, as long as, the vehicle is exposed to the solar. This implies that the solar energy is basically the primary source energy that powers the system. In addition to the solar energy source, electrical energy from the mains supply is allowed to enhance the charging of the battery bank where no solar is readily available perhaps due to cloud or rain. Thus, the electrical main supply act as a back-up power supply source.

The braking system of the vehicle would be requiring hydraulics in view of excellent characteristics of hydraulic as an efficient braking medium. The advantages includes: easy of transmission, high transmission co-efficient, little or no transmission loss, high reliability and respective actuation. Electric braking system was dropped due high energy loss ratio compared to hydraulic braking system. Systems are installed on the dashboard for easier and quicker operation ability. The vehicle is design to run even during the dark or night hours, hence electrical lighting system was incorporated including head lamps and trafficators. Being an electrical system makes precise calculations of the ratings of these major components of the car imperative at the design stage. The ratings of the 3- major components of the car that will be determined are

1. The motor power rating required to achieve the necessary speed and acceleration
2. The battery capacity which can support distance required to be travelled
3. The solar panel specification needs to keep the battery sufficiently charged for the journey.

3.2 Motor Power rating

The power needed to propel a vehicle can be determined by combining the forces that needs to be applied to the vehicle to move it with the vehicle speed at which this propelling force must be sustained. The drive torque generated by the motor for the wheels produced a drive force at the tyre/road contact. It is this drive force that moves the vehicle. At the design stage it's easier to frame the calculation around this drive force rather than the drive torque. The total drive force that has to act on the vehicle to make it move (or keep it moving can be estimated by adding together individual force to overcome the rolling resistance of the wheels on the drive surface force to overcome aerodynamic drag and force to accelerate the vehicles mass.

3.2.1 The Rolling Resistance

The resistance force is the frictional force resisting the rolling motion of the tires as they roll over the road surface. A rubber tire will have higher rolling resistance on a paved road than a steel rail road wheel on a steel rail similarly, sand on the ground will give more rolling resistance than concrete. The rolling resistance force can be expressed as

$F_{ROLLING} = \mu_R W$

Where W is the weight of the car i.e. $W = mg$ and μ_R is the coefficient of rolling resistance and is a constant that depends in the type of tires of the vehicle and the surface on which it will roll to conserve power solar cars need to use thinner tires, because thicker tires produce more solar cars need to use thinner tires, because thicker tires produce more rolling resistance, although, they goods for adhesion, also, harder surfaces offer lower rolling resistance force than softer ones.

μ_R for ordinary car tires on concrete ranges in value from 0.010 to 0.015 while that on sand is of value 0.3

$$F_{ROLLING} = mg\mu$$
$$500x9.81x0.01$$
$$= 49.05N$$

3.2.2 Aerodynamic Drag Force (Air Resistance)

The aerodynamic drag force or air resistive force is simply the force exerted by the air to prevent the vehicle from moving through it. The aerodynamic dynamic drag force can be expressed as,

F_{DRAG} = ½ C_D is the coefficient of drag of the vehicle
C_D for Jeep like cars = 0.85
C_D for Hilux like cars = 0.45
C_D for Normal car = 0.32
A_{cross} is the frontal area = 1m x 1.1 m = 1.1m^2
P is a constant that account for the air mass density = 1.2 kgm^{-3} and V is the vehicles speed = 60km/h = 16.7m/s
To minimize drag from any given C_D, the coefficient of drag and A_{cross}, its frontal area must be minimized.
F_{DRAG} = ½ x 0.32 x 1.1 x 1.2 x 16.72
=58.9N

The drag force becomes increasingly noticeable at speeds of above 40km/h due to it being proportional to the square of the speed.

3.2.3 Force of acceleration

The force of acceleration should be only accounted for when the car is accelerating and is given by Newton's 2nd law of motion

$$F_{ACCELERATION} = ma\ (by\ modelling\ (a = dv/dt) = 3.11 - 0.000137V^2$$
$$For\ \leq 19.8m/s(71.3kph)$$

$where\ m\ is\ the\ mass\ of\ the\ car\ and\ a'is\ the\ acceleration$

Where m is the mass of the car and a is the acceleration $a = \left(\frac{v-u}{t}\right)$ In a busy street of Bauchi state,. Especially at rush office hours, it is hardly possible to accelerate freely without being impeded by traffic. Thus assuming an acceleration time of 1.5 minutes to accelerate freely from 0 to 60km/h would suffice

$$a = \frac{v-u}{t} = \frac{16.7-0}{1.5x60} = \frac{16.7}{90} = 0.186m/s^2$$

$$F_{ACCELERATION} = 500\ x0.186$$
$$= 93N$$

The total driving force thus required to overcome the sum of these opposing forces to move the car is

$$F_T = F_{ROLLING} + F_{DRAG} + F_{ACC}$$
$$49.05N + 58.9N + 93N$$
$$200.95N$$

The power needed to be supplied by the motor in order to provided the current speed and acceleration will therefore be:

$$P_T = F_T V$$
$$= 200.95\ x\ 16.7$$
$$= 3355.865W$$
$$4kW\ motor\ is\ chosen$$

A motor with power rating of 3.5kW will be required to accelerate the car from) to 60km/h but instead a motor with rating of 1.5kW is used coupled to a gear system of ration 23:1 the note to be made here is that although the calculation showed live need a higher power motor, but due to lack of availability this system is adopted.

3.3 Battery Capacity

Capacity is the measurement of how much energy the battery can contain is (Ampere-hours), analogous to the amount of water in a jug. The capacity required will be dependent on the cars acceleration and speed as well as the total distance the car will overcome before the battery charge is deplete. In perspective of Bauchi state let assumed a distance of 35km. in the design stage a rough estimation of the minimum battery capacity necessary for this trip has to be obtained. To calculate this, the journey is divided into (3) sections each with its own speed and the average and the average is taken as follows

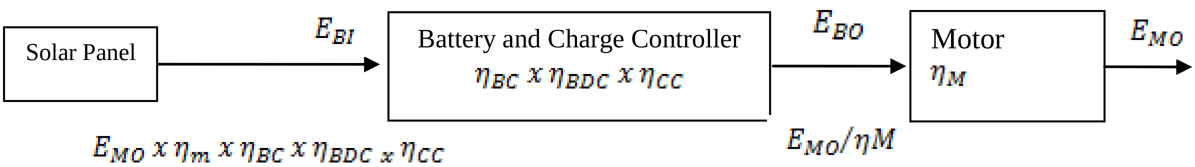

Fig 3.1: System diagram solar panel, battery and Motor Now, taking into consideration the system diagram, the battery output and, consequently input energy required can be calculated.

Where the following assumptions were made

Motor efficiency $\eta_{AA} = 90\%$

Battery discharging efficiency $\eta_{BDC} = 90\%$

Battery charging efficiency $\eta_{BC} = 90\%$

Charge controller efficiency $\eta_{CC} = 90\%$

Depth of discharge, $D.O.D = 80\%$

Total Battery Voltage, $V_B = 12\ x\ 5 = 60\%$

Battery output energy required, $E_{BO} = E_{MO}/\eta_M$

Where E_{MO} = total motor output energy

To calculate E_{MO} the car journey is divided into 3 =sections each with its own speed and the average is taken

Total power= 4kW
Max. Distance = 35km
Top speed, V = 60km/h

Max speed P=1.9kW 40% of the journey Motor Energy needed,

$(kWh) E_{MO} = Px\, d/v = pxt$

Speed V (km/h)	Power (kW)	Distance (km)	Motor Energy Needed
Max. Speed V = 60km/h	P= 1.9kW	40% of the journey i.e 40/100 x 35 = 14km	E_{MO}= 1.9x 14/60 = 0.433kWh
½ of max. speed V = 30km/h	P= 0.54kW	40/100 of the journey = 14km	0.54 x 14/30 0.253kWh
Cruising speed V = 10km/h	P =0.14kW	20% of the journey = 20/100 x 35 = 7km	0.099kWh
Total motor output energy, E_{Mo}			0.795kWh

$$E_{BP} = E_{MO}/\eta_m = \frac{0.795}{0.9} = 0.883kWh$$

Battery output energy required, $E_{BO} = 0.883kWh$

Battery input energy required, $E_{B1} = E_{M0}/\eta_{m\ x}\, \eta_{BC}\ \ x\, \eta_{BDC}\, x\, \eta_{CC}$

$$0.795/0.9\ x\ 0.9\ x\ 0.9\ x\ 0.9\ x\ 1.21kWh$$

$$Battery\ capacity\ C_B = \frac{E_{B1}}{D.O.DxV_B} = 1.21\ x\frac{10^3 V_a h}{0.8x60} = 25.2Ah$$

The car however is expected to accelerate numerous times during the journey which will deplete more energy from the battery. Thus a battery capacity of roughly 3 times higher

$i.e\ 25.2\ Ah\ x\ 3 = 75.6Ah$

70 Ampere – hour is chosen for market availability

3.4 Panel Wattage

The total energy required from the output of the solar panels

$$Panel\ output\ energy = E_{P0} = E_{B1} = 1.21kW$$

In Bauchi state, the solar insulation (solar radiation energy received) on average corresponds to $7kWh/kW$ therefore, the minimum required panel wattage is,

$$PW = \frac{E_{PO}}{7} = \frac{1.21x10^3}{7}$$

$$= 172.86W$$

To account for the acceleration of the car the actual value chosen for the panel wattage was 2 panels of 100W each i.e. 2 x 100 = 200W

Picture 1: Frame and the Chassis of the Solar Power Cart

Picture 2: The Solar Panel Mounted at Angle 90^o on the Vehicle

4.0 Conclusion and Recommendation

The conventional cars' exhaust fumes today are one of the biggest contributions to the atmospheric CO_2 as illustrated in figure 1.1. The global warming resulting from this causes global temperatures to increase and consequently raise the sea level as well.

Ultimately electric vehicles may be of substantial benefit, reducing harmful emissions. There is considerable misunderstanding at present as to precisely why electric vehicles can be of benefit and the extent of that benefit [7]. The electric solar vehicle may definitely be a major step in reducing the global warning, traffic congestion, noise and vehicle emissions on the road

The electric solar vehicles will cost four times less than fuel-based cars since apart from the initial cost of the major components of installation for example the solar panels, charge controller and motor controllers, there would e no more recurring cost as solar energy is absolutely free. If the government and many transportation industries can take the initiative to produce solar power and thus to the production of electric solar vehicles at large scale, the use of this modern vehicle will benefit us all.

References

[1]. Goetz Berger, crystalline silicon solar cells: past, present, future, www.onlinelibrary.wiley.com accessed on 11 January 2018.
[2]. James, Larminie, Electric vehicle Technology explained, 2003, pp245.
[3]. Kribus A, high-efficiency triple cycle for solar power generation ,2002
[4]. Ndaceko U. I, Solar Energy potential in Nigeria, International Journal of Scientific & Engineering Research, Volume 5, Issue 10, October-2014, pp594
[5]. REGEN sustainable power solution, Solar photovoltaic power system handbook, Regen power pty. Ltd, 2011 pp4.
[6]. Richard Komp, panel works, www.edited.com/lesson/how-do-solar accessed 5 January 2016.
[7]. Yathishal, Eco-friendly car using solar and electricity energy, international Research Journal of Engineering and Technology (IRJET) volume: 02 Issue: 03/June, 2015 pp 2162 www.irjet.net.