International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 08, August-2019

Design and Development of Solar Powered Vehicle

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***Abstract*— Battery powered electric bikes are replacing the heavily polluting internal combustion engines nowadays, provided zero emission transportation in many parts of the world. Tremendous economic growth resulting in increased authorization and spatial expansion of cities are becoming longer and more difficult to make. As a result our electric powered two wheelers tend to be more efficient and produce less air pollution per km than any other modes, hence it will increase mobility and accessibility to opportunities due to increase in speed and range. Battery powered vehicles are nowadays replacing heavily polluting bikes with 4 stroke engine , provide zero emission transportation just because of time required to charge batteries and lack of charging infrastructure it is not accepted by many people till date. Sustainable and practical personal mobility solutions for cities environments have traditionally revolved around the use of bicycles, or provision of pedestrian facilities. However many cities also experience traffic congestion, parking difficulties and pollution from fossil-fuelled vehicles. It appears that pedal power alone has not been sufficient to supplant the use of petrol and diesel vehicles to date, and therefore it is opportune to investigate both the reasons behind the continual use of environmentally unfriendly transport, and consider potential solutions.**

The main objective of the project is to use outgoing solar energy as a source to run a two wheeled motor bike. This project aims to create a pollution free solar powered vehicle. The main aim of this project is to make a hardware model of Solar Electric Vehicle, with an intention to reduce total carbon emission created by fossil fuel vehicles. We have tried our best to make the vehicle the symbol of greener surroundings. This project is a way of using the outgoing power and producing from solar panel. This project consists of a rechargeable battery pack which powers a light weighted motor unit over the wheel. The solar electric bicycle approach is different. To overcome the problem and the weakness, this project need to do some research and studying to develop better technology. . The main aim of this project is to make a hardware model of Electric Vehicle, with an intention to reduce total carbon emission created by fossil fuel vehicles. We have tried our best to make the vehicle the symbol of greener surroundings. It also aims to showcase This vehicle enhances in rapid growing steps towards a green future. The electric vehicle uses Batteries, Motor, Controller, Speed Control Unit, Battery Charger Unit and throttle. To make it success there are several thing that we need to know such as what will be the prime mover, how to store it and the advantages of this new vehicle.

Keywords—Battery, Speed Control Unit, fossil fuelled.

I. INTRODUCTION

The solar electric bicycle is meant as a challenge to get, on sunny summer days, the most pedal assistance as possible out of the solar panel used. The solar electric bicycle is sportive. It may not cost substantially more energy to drive the solar electric bicycle, when not powered, than a normal bicycle. When there is no sunlight or the batteries are empty the bicycle should still be light running. E-bikes need large and heavy batteries to allow riding long distances, because the battery is charged only once at home.

The solar bike approach is different. The PV panels have enough power and give the bicycle an infinite range. The battery is small, and saves weight. Without sun however, the battery can be fast charged en route in about 30 minutes because 12V 12 Ah * 2 LA batteries and 220V AC, 50 Hz, 1.0A charger allow fast charging. Although, we need a location, for instance a café that allow us to use the mains. Another method is by charging the battery through a homemade windmill using a fan or a 24V DC fan (a prototype of the fan has been shown in the bicycle). The fan is placed above the front wheel of the bicycle and is connected to one of the 12V battery placed in the bicycle. The battery will be charged while the bicycle is running. This way of charging the battery will be very useful during cloudy day. The purpose of the solar bike is not energy saving. A bike is very energy efficient. The cost of the electrical energy that would be needed to cycle a whole day is very less. In terms of energy savings, this is negligible. A solar bicycle or tricycle has the advantage of very low weight and can use the rider's foot power to supplement the power generated by the solar panel roof. In this way, a comparatively simple and inexpensive vehicle can be driven without the use of any fossil fuels.

The solar electric bicycle is easily accessible, safe and practical with limited maintenance requirements due to a minimum of mechanical parts used. It is ideal not only for the experienced cyclists but also for those non-athletes, the elderly and individuals with health problems. A solar vehicle is an electric vehicle powered completely or significantly by direct solar energy. Usually, photovoltaic (PV) cells contained in solar panels convert the sun's energy directly into electric energy. The term "solar vehicle" usually implies that solar energy is used to power all or part of a vehicle's propulsion. Solar power may be also used to provide power for communications or controls or other auxiliary functions. Solar vehicles are not sold as practical day-to-day transportation devices at present, but are primarily demonstration vehicles and engineering exercises, often sponsored by government agencies. However, indirectly solar-charged vehicles are widespread and solar boats are available commercially.

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1.1 Introduction to E-Bike:

A brushless DC motor (BLDC) is a synchronous electric motor which is powered by direct-current electricity (DC) and which has an electronically controlled commutation system, instead of a mechanical commutation system based on brushes. In such motors, current and torque, voltage and rpm are linearly related. BLDC has its own advantages such as higher efficiency and reliability, reduced noise, longer lifetime, elimination of ionizing sparks from the commutator, and overall reduction of electromagnetic interference (EMI). With no windings on the rotor, they are not subjected to centrifugal forces, and because the electromagnets are located around the perimeter, the electromagnets can be cooled by conduction to the motor casing, requiring no airflow inside the motor for cooling. The disadvantage is higher cost, because of two issues. First, it requires complex electronic speed controller to run.

II. CONTROL THEORY

2.1: Control theory

It is an interdisciplinary branch of engineering and mathematics that deals with the behavior of dynamical systems. The desired output of a system is called the reference. When one or more output variables of a system need to follow a certain reference over time, a controller manipulates the inputs to a system to obtain the desired effect on the output of the system.

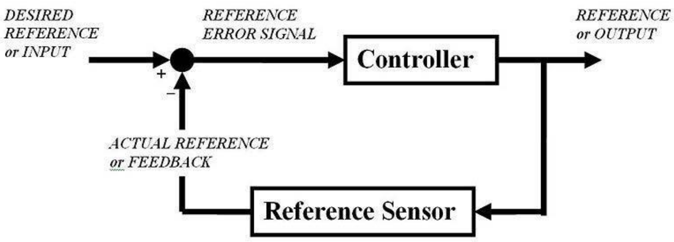

Figure 1: Concept of the Feedback Loop to Control the Dynamic Behavior of the Reference

If we consider an automobile cruise control, it is design to maintain the speed of the vehicle at a constant speed set by the driver. In this case the system is the vehicle. The vehicle speed is the output and the control is the vehicle throttle which influences the engine torque output. One way to implement cruise control is by locking the throttle at the desired speed but when encounter a hill the vehicle will slow down going up and accelerate going down. In fact, any parameter different than what was assumed at design time will translate into a proportional error in the output velocity, including exact mass of the vehicle, wind resistance, and tire pressure. This type of controller is called an open-loop controller because there is no direct connection between the output of the system (the engine torque) and the actual conditions encountered; that is to say, the system does not and cannot compensate for unexpected forces.

For a closed-loop control system, a sensor will monitor the vehicle speed and feedback the data to its computer and continuously adjusting its control input or the throttle as needed to ensure the control error to a minimum therefore maintaining the desired speed of the vehicle. Feedback on how the system is actually performing allows the controller (vehicle's on board computer) to dynamically compensate for disturbances to the system, such as changes in slope of the ground or wind speed. An ideal feedback control system cancels out all errors, effectively mitigating the effects of any forces that may or may not arise during operation and producing a response in the system that perfectly matches the user's wishes.

2.2 Closed-Loop Transfer Function:

The output of the system *y(t)* is fed back through a sensor measurement *F* to the reference value *r(t)*. The controller *C* then takes the error *e* (difference) between the reference and the output to change the inputs *u* to the system under control *P*. This is shown in the figure. This kind of controller is a closed-loop controller or feedback controller. This is called a single-input-single-output (*SISO*) control system; *MIMO* (i.e. Multi-Input-Multi-Output) systems, with more than one input/output, are common. In such cases variables are represented through vectors instead of simple scalar values. For some distributed parameter systems the vectors may be infinite-dimensional (typically functions)

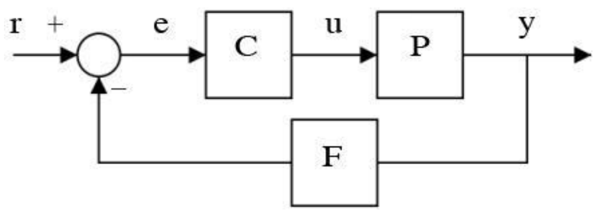

Figure 2: Closed-loop controller or feedback controller

2.3 PID Controller:

PID Control (proportional-integral-derivative) is by far the widest type of automatic control used in industry. Even though it has a relatively simple algorithm/structure, there are many subtle variations in how it is applied in industry. A proportional–integral–derivative controller (PID controller) is a generic control loop feedback mechanism widely used in industrial control systems. A PID controller will correct the error between the output and the desired input or set point by calculating and give an output of correction that will adjust the process accordingly. A PID controller has the general form

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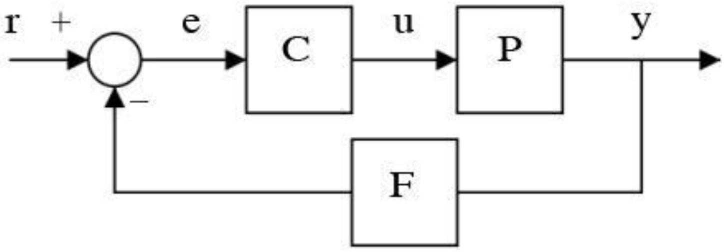

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$$\mathrm{u}(\mathrm{t}) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{de}{dt}$$

Where K_p is proportional gain, K_i is the integral gain, and K_d is the derivative gain.The PID controller calculation (algorithm) involves three separate parameters; the Proportional, the Integral and Derivative values [1]. The Proportional value determines the reaction to the current error, the Integral determines the reaction based on the sum of recent errors and the derivative determines the reaction to the rate at which the error has been changing [1]. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, the power supply of a heating element or DC motor speed and position.

2.3.3 Pulse Width Modulation:

Pulse-width modulation (PWM) of a signal or power source involves the modulation of its duty cycle, to either convey information over a communications channel or control the amount of power sent to a load.

Pulse-width modulation uses a square wave whose pulse width is modulated resulting in the variation of the average value of the waveform. If we consider a square waveform *f*(*t*) with a low value y_{min}, a high value y_{max} and a duty cycle D (see figure 2.3), the average value of the waveform is given by:

$$\bar{y} = \frac{1}{T} \int_0^T f(t)\, dt$$

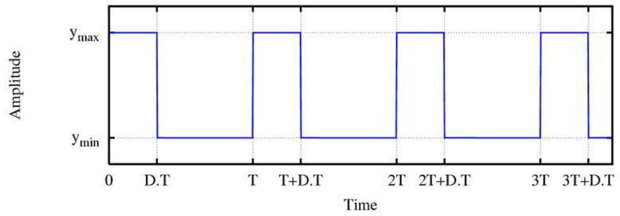

Figure 4: A Square Wave, Showing the Definitions of y_{min}, y_{max} and D

As *f*(*t*) is a square wave, its value is y_{max} for

$0 < t < D \cdot T$ and y_{min} for

$D \cdot T < t < T$. The above expression then becomes:

$$\begin{aligned} \bar{y} &= \frac{1}{T}\left(\int_0^{DT} y_{max}\, dt + \int_{DT}^{T} y_{min}\, dt\right) \\ &= \frac{D \cdot T \cdot y_{max} + T(1-D) y_{min}}{T} \\ &= D \cdot y_{max} + (1-D)\, y_{min}. \end{aligned}$$

This latter expression can be fairly simplified in many cases where $y_{min} = 0$ as $\bar{y} = D \cdot y_{max}$. From this, it is obvious that the average value of the signal ($\bar{y}$) is directly dependent on the duty cycle D.

The simplest way to generate a PWM signal is the interceptive method, which requires only a saw tooth or a triangle waveform (easily generated using a simple oscillator) and a comparator. When the value of the reference signal (the green sine wave in figure 2.4) is more than the modulation waveform (blue), the PWM signal (magenta) is in the high state, otherwise it is in the low state.

III. SOLAR BICYCLE-BATTERY TYPE:

The solar bike can be equipped with two kinds of batteries with their own specific requirements:

- Short-term storage for the solar energy. This battery is continuously charged and discharged and should therefore have a high cycle life. Also, a high charge / discharge efficiency is important here.
- Long-term storage for charging at home. This battery is not as heavily stressed as the short-term battery. Here, low weight is important.

Both batteries must allow fast charging

3.1 Solar Panel:

A solar panel (photovoltaic module or photovoltaic panel) is a packaged, connected assembly of solar cells, also known as photovoltaic cells. The solar panel can be used as a component of a larger photovoltaic system to generate and supply electricity in commercial and residential applications.

Because a single solar panel can produce only a limited amount of power, many installations contain several panels. A photovoltaic system typically includes an array of solar panels, an inverter, and sometimes a battery and interconnection wiring.

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In this project two solar panels of 40Watts each which is connected to a 12V battery which helps in continuous charging of the battery. Solar panels use light energy (photons) from the sun to generate electricity through the photovoltaic effect. The structural (loadcarrying) member of a module can either be the top layer or the back layer. The majority of modules use wafer-based crystalline silicon cells or thin-film cells based on cadmium telluride or silicon. The conducting wires that take the current off the panels may contain silver, copper or other non-magnetic conductive transition metals.

3.1.1 Solar Photovoltaic:

Solar photovoltaic (PV) panels are the most common solution for people interested in harnessing the suns energy. Not only are photovoltaic panels the ideal solution for generating renewable energy in the home or workplace but they are also ideal for generating a source of electricity in areas where electricity supplies don’t currently exist (such as remote communities). The best example of the harnessing solar energy to provide electricity in remote locations can be found in space as for many years, satellites have been using solar panels to catch the sun’s rays to provide power to the equipment on board.

Photovoltaic panels can be installed as single devices or as part of what is called an “array”. The big advantage of installing solar PV panels in an array is down to the ability to generate more power from one system instead of having to install complete separate solar PV systems for each panel used. The installation of a solar electricity system is still a viable option to provide a substantial amount of electricity helping to reduce energy bills over the period of operation for a home or business.

Therefore, a solar panel of 80w which produces 5A per hour is selected for our 15Ah battery which gets charged in 3 hrs. Due to size considerations two solar panels of 40w each are used in our solar bike. The PV panel is the part of the PV prototype system which generates electrical energy by using the irradiance of the sun. The maximum power (or peak power indicated with Wp) of a PV panel depends basically on the type of panel and on the dimensions and is given for an irradiance of 1000W/m².

Figure 5: Solar panel used in the solar electric bicycle

Some producer dependent parameters affect the efficiency of a new panel. Due to degradation of the active material, soiling and other influences the peak power of PV panels decreases with the years. The power P_{PV} [W] which a PV panel can generate always depends on the peak power P_{peak} [W] and on the prevailing irradiance G [W/m²]: For P_{peak} = 55W; G = 200W/m² (barley enough irradiance to effect shadings)$P_{pv}=P_{peak}\times$ (G/1000w/m^2).That means, at a prevailing irradiance of 200W/m² a 55Wp module generates in maximum about 11W.

Another important fact is that (in most cases of mono crystalline Si panels) the whole panel has to be illuminated with the same irradiance to deliver the assumed power. If only one cell (part) of the panel has an area of less irradiance – due to partial shading – this has a disproportionate impact on its power production (Deline, 2009). This effect has a big influence on the possible electricity generation on the bike because the panel often is shaded by the driver or the surrounding. The PV panel which is used in the PV prototype system is a 55Wp module which is built of Si mono crystalline cells. It has 2 bypass diodes build in the connection box to improve the performance when it comes to partial shading on a half of the panel. It is chosen because its dimension fits with 985mm times 440mm very good on the available space of the bike.

IV. SOLAR BICYCLE-BATTERY TYPE SELECTION OF THE BATTERY:

4.1 Voltage:

Battery packs are made up of individual cells connected together. Each cell has a more or less constant voltage dependent on its chemistry. For NiCad/NiMH, this is about 1.2V, for lead acid it is 2.0V, and for lithium cells it is on the order of 3.7V. Typical ebikes and scooters are designed to run on 24, 36, or 48 Volts, so a number of cells have to be series connected into a 'battery' that has the desired net voltage. A nominal 36V pack could be made from 10 lithium cells, 18 lead acid cells, or 30 NiMH cells.

4.2 Amp-Hours:

As we draw current from a battery pack, the voltage will very slowly decrease until the cells start to go flat and then the voltage will plummet. The time that the battery lasts for is directly related to its capacity, measured in amp-hours (Ah). A pack that can deliver 1 amp for 1 hour has a capacity of 1 Ah. Most ebike batteries are on the order of 10 amp-hours. To a first order, twice the amp-hours would mean twice the size, twice the weight, and twice the cost. In practice this deviates a little due to different packing densities and production scales, but it's usually pretty close. For instance, the familiar 'AA' NiMH has about
2 Ah, a 'C' cell has 4 Ah, a 'D' cell is about 8Ah, the large 'F' cells are 12-13 Ah, and double-D cells are 18-19Ah.

4.3 Watt Hours:

The figure that matters most when comparing how far a given battery pack will take you is not the amp-hour capacity but the total energy stored watt-hours. To make things more familiar, one watt-hour is one-thousandth of a kWh, the unit of energy used to measure household electrical usage. The watt-hours stored in a battery pack is approximated by taking the actual amp-hours and multiplying it by the pack voltage. A higher voltage setup therefore needs fewer amp-hours to deliver the same range. So a 24V 8Ah battery can deliver 192 watt-hours, while a 48V 4Ah pack also has 192 watt-hours. Assuming that both batteries are of the same chemistry, then you could expect they would weigh the same, cost the same, and provide the same performance on appropriately designed ebikes (i.e., one designed for 24V and the other for 48V). 192 watt-hours is about the smallest battery size you would want for an ebike. Many of the store-bought ebikes have about this much capacity since it keeps the battery cost down. For people who want to actually commute reasonable distances of 40-50km, then I would recommend on the order of 400 watt-hours. While it can vary a lot with usage habits, an energy consumption of 9-10 watt-hrs / km is typical on normal direct-drive setups.

4.4 Energy Density:

When comparing between battery chemistries, one of the most relevant metrics is the Energy Density in watt-hrs / kg. This figure says how heavy a battery pack will have to be to achieve a certain range. For Lead Acid it is 20-30 watt-hrs/kg, for NiCad it is 35-40 watt-hrs/kg, NiMH is 50-60 watt-hrs/kg, Li-ion is ~110 watt-hrs/kg, and Li-Polymer is up to 160 watt-hrs / kg. Knowing these values makes it easy to project the weight of a pack without having to look up data from the manufacturer.

4.5 C Rate:

One term you will frequently come across is the 'C' rate of a battery pack. This is a way of normalizing the performance characteristics so that batteries of different capacity are compared on equal terms. Suppose you have an 8 amp-hour pack. Then 1C would be is 8 amps, 2C would be 16 amps, 0.25C would be 2 amps etc. A higher 'C' rate of discharge is more demanding on the cells, and often requires specialty high rate batteries. For example, suppose you see a 24V 4Ah NiMH battery pack on ebay, that is rated for 1C continuous and 2C max for short times. You might want to get two of these to make a 48V 4Ah battery for your ebike. You calculate that the range will be more than adequate for your short commute to work and back. The problem is that 1C is just 4 amps, while your ebike will probably draw 10-20 amps. If these cells are subject to such discharge rates, then the voltage will sag considerably, leading to slower performance, and the cycle life of the packs will be greatly reduced. Most inexpensive NiMH packs are not really designed for discharges greater than 1C. That means that if your ebike draws 15 amps on average, you would want a pack that has a capacity on the order of 15 amp-hours more.

4.6 Power of Motor:

Kinetic Energy= $m\Delta V^2$

Electrical Energy=V·I·T

K.E.=

Voltage rating motor × Current required ×
time to accelerate

Power required at different accelerations
=(kinetic energy) /(time to accelerate)

K.E.=

Power of Motor=[(1⁄2×m×V^2)]÷t

i.e. $[(1/2)\times120\times8.33^2]\div5 = 833.32$ watts

m- mass of vehicle with rider (in kg); V- change in velocity required (in m/s); t- time required to accelerate from 0 (in seconds)

similarly, when acceleration time is increased to 8 sec and 12 sec, we get power of motors to be used as 520 watts and 347 watts.

4 .7 Current drawn by motor:

Power of motor = voltage×current (of battery)

P=V×I: 833.32 watts = 48V×I Therefore I=17.3A

P- power of motor (in watts)

V= rated voltage of battery (48v)

I= current drawn from battery

A 800 Watt motor was used to meet our system requirements. Given the terrain that the bike would normally be ridden on these requirements would only be relevant over intermediate duties. Furthermore, a 800 Watt motor is more than sufficient for continuous operation.

Table 1: Power requirements of the Motor

Time to accelerate (s)	ΔVelocity	Voltage Available (V)	Mass Kgs	Current Required(amps)	Power Consumed (Watts)
5	30kmph	48	120	173	833.32
8	30kmph	48	120	10.85	520.8
12	30kmph	48	120	7.2	347.2

Table 2: Hill-climbing power requirements

Speed (Max)	**Voltage Available (V)**	**Mass (Kg)**	**% Gradient**	**Current (amps)**	**Power (Watts)**
30 kmph (8.33 m/s)	48	120	5	18.3	655.2
30kmph (8.33 m/s)	48	120	10	34.6	1310.4

As we can observe from calculated table, using a motor of 800w gives us the best required output. We can also choose motors of 500w but it takes larger time to accelerate which causes loss of power. $gradient = \sin\theta$ =

Hill Climbing Energy Requirements:

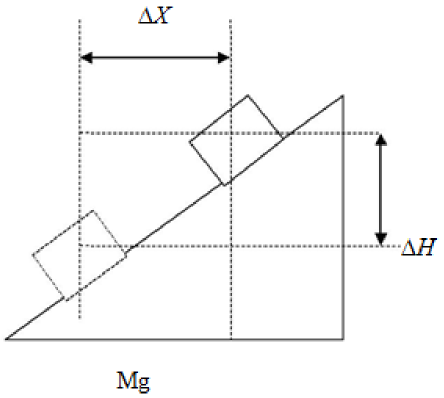

Figure 6: Model of Hill-climbing

So, by observing the above results BLDC hub motor of 800w is selected due to following reasons

- Ability to fit inside a wheel and reduce space
- Good torque-Speed relationships
- High-power – weight ratio
- Past experience through Control Theory
- Ease of motor characterization (solving for torque constant, back-emf constant, voltage-speed constant)
- Easy to control.

V. ASSEMBLY OF BLDC MOTOR AND REAR WHEEL:

The driving source of the vehicle is the brushless DC motor which is controlled by an electronic controller. This BLDC motor needs to be assembled with the rear wheel of the vehicle for the transmission of power from motor to wheel. Since the motor used is brushless type, it can be directly fitted with the shaft of the wheel. This avoids mechanical transmissions such as chain-sprockets or belts. Hence the power loss is reduced. A rim is provided on the outer surface of the motor which can be attached with rim of the rear wheel of the vehicle. By taking appropriate measurements, holes are drilled on the rim of the motor. The wheel is attached by using suitable length of spokes which are inserted in the holes drilled on the motor. The existing spokes and the hub of the wheel of a motorcycle are removed and the wheel is made hollow. It just has the rim and the rubber wheel on the exterior side. The motor is placed at the center of the wheel. To have perfect circular rotation the wheel and the motor needs to be aligned on a single straight line. So the center of the wheel is known and the motor is placed such that the center of the motor perfectly coincides with the center of the wheel. The distance between the outer surface of the motor and the inner surface of the wheel is calculated and the spokes of the suitable length are fitted between them. Length of the spokes must remain constant so that the distance between the motor and the wheel remains constant.

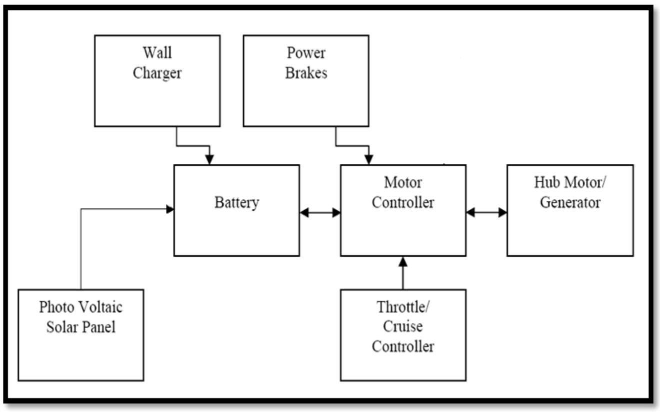

Figure 7: Block diagram for solar vehicle

The designs of the different parts of the rear wheel assembly are shown in below figures:


Figure 8: Wheel of the Motorcycle

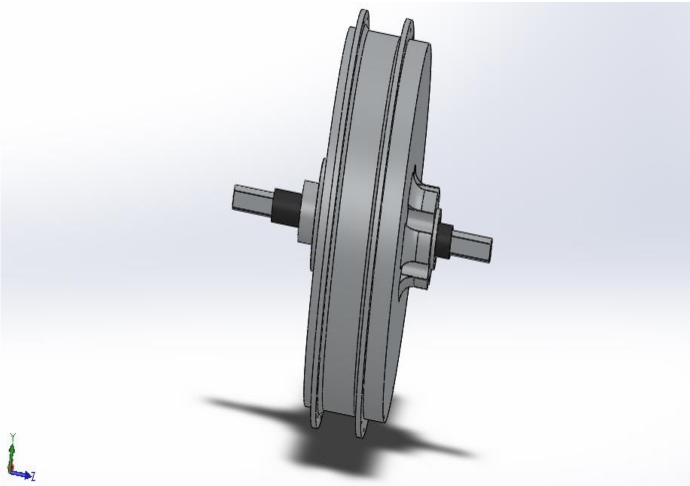
Figure 9: BLDC Motor

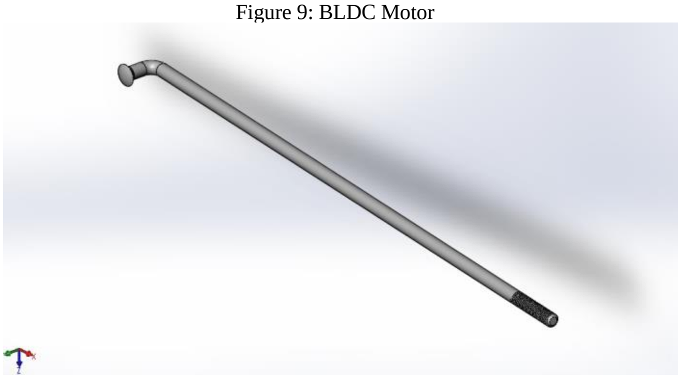
Figure 10: Design of Spoke

Figure 11: Final assembly of rear wheel

The assembled model is shown in below figure:

Figure 12: BLDC motor incorporated in wheel

5.1 Fabrication of Vehicle:

The fabrication process involves fixing the different components to the frame of the bicycle. The motor is fixed to the rear wheel shaft with proper alignment so that the weights are perfectly balanced. A battery casing in which 4 LA batteries of 12 V and 15Ah are fixed to frame and wirings are drawn from battery to motor so as to transmit power from battery to motor. Also wiring for speed control is also incorporated. Two solar panels are mounted on the either side of the vehicle. A solar charge controller is connected between the battery and solar panel. This charge controller ensures the charging of the battery. The solar charge controller stops charging the battery which it reaches its maximum voltage

Figure 13: Final Assembly of the Solar Vehicle

The Major components of the solar vehicle include:

- Prime Mover-Brushless DC Motor
- Motor Specifications-800Watts
- Power Source-Lead Acid Batteries (4 in number)
- Battery Type-Rechargeable
- Battery Specifications- 12v 17Ah
- Charging Source-Solar Panels
- Controller-Amptek Motor Controller 48v 20amps
- Throttle-Electronic PWM type.
- Tyre size-18inches
- Load Capacity-140kg

VI CONCLUSIONS

Solar powered motor bike is modification of existing bike and driven by electrical energy. It is suitable for both city and country roads, that are made of cement, asphalt, or mud. This bike is cheaper, simpler in construction & can be widely used for short distance travelling especially by school children, college students, office goers, villagers, postmen etc.

It is very much suitable for young, aged, handicap people and caters the need of economically poor class of society. It can be operated throughout the year free of cost. The most important feature of this bike is that it does not consume valuable fossil fuels thereby saving a lot on fuel expenses. It is eco-friendly & pollution free, as it does not have any emissions. Moreover it is noiseless and can be recharged with the AC adapter in case of emergency and cloudy weather. Sustainable and practical personal mobility solutions for cities environments have traditionally revolved around the use of bicycles, or provision of pedestrian facilities. However many cities also experience traffic congestion, parking difficulties and pollution from fossil-fuelled vehicles. It appears that pedal power alone has not been sufficient to supplant the use of petrol and diesel vehicles to date, and therefore it is opportune to investigate both the reasons behind the continual use of environmentally unfriendly transport, and consider potential solutions.

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The conclusions traced out after the successful completion of the project are as follows:

- The use of solar powered vehicle is the best way to reduce environmental pollution which is caused by the present day automobile emissions.
- This vehicle is comparatively cheap and simpler in construction.
- The motorcycle can run for 4 hours or 50 km range on full charge with an average speed of 35kmph.
- Solar power is abundant in nature and is easily available everywhere whereas fossil fuels are available at specific locations. Hence use of solar over fuels is a major advantage.

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