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On the run charging solar vehicle

Development and construction of a solar vehicle without any complexity in charging the batteries

This report contains the technical and physical details of all the equipment that are used in the construction of the vehicle. The electrical equipment in the vehicle includes solar panels, solar charge controller, BLDC motor, motor controller, batteries and speed control while the mechanical apparatus includes a simple steering system, braking system, suspension system, materials to be used and the chain drive system.

1 Introduction

In this world of fuel and gas powered vehicles, there is an increasing need for reduction of environmental pollution by limiting the release of greenhouse gases into the environment. Solar electric vehicle is one of the present day world's best idea of reducing the pollution and use of fossil fuels. There are many ways of building an electric vehicle. Some of the ways in which this problem is addressed is by charging the batteries using electricity in residences and placing them in vehicles which is a tiring job as the batteries are heavy and the user is paying for the charging of batteries. Charging the batteries using solar panels which are kept in an appropriate place and then using them in vehicles is a debatable idea considering the weight of the batteries and the possibility of unavailability of solar panels at the destination. Directly using the solar panels on the vehicle to run the motor is a limited approach as a large number of panels are required to run a high capacity motor and the vehicle stands constrained to work only when the solar panels are producing some power. Considering all these, this report concentrates on using solar panels on the vehicle to charge a high capacity battery which can be used at all times of the day and night which can also be helpful for long journeys.

2 Circuit Design

The electrical components and the electrical circuit design are the most important parts of the solar vehicle. The design is shown in the fig.1. The solar panels form the first part of the electrical design of the system. They are to be mounted on top of the solar vehicle where the sunlight is largely concentrated on. The solar panels are connected directly to the solar charge controller which is manufactured according to the required specifications. The solar charge controller uses its first two ports for intake of power from the solar panel which is stored in the batteries. The charge produced by the batteries to run the motor is controlled by the solar charge controller. The motor controller is connected to the solar charge controller. While the solar charge controller regulates the power with which the motor runs, the motor controls the working of the BLDC motor (Brushless Direct Current motor). The motor controller is also provided with auxiliary connections such as speed control of the motor, forward and reverse switch, lights and horn. The connection between every two components is protected by using fuses or MCBs (Miniature Circuit Breaker). Although it is not mandatory to use LED detection for every connection, it is highly recommended to use both fuses and LEDs between batteries and solar charge controller and also between

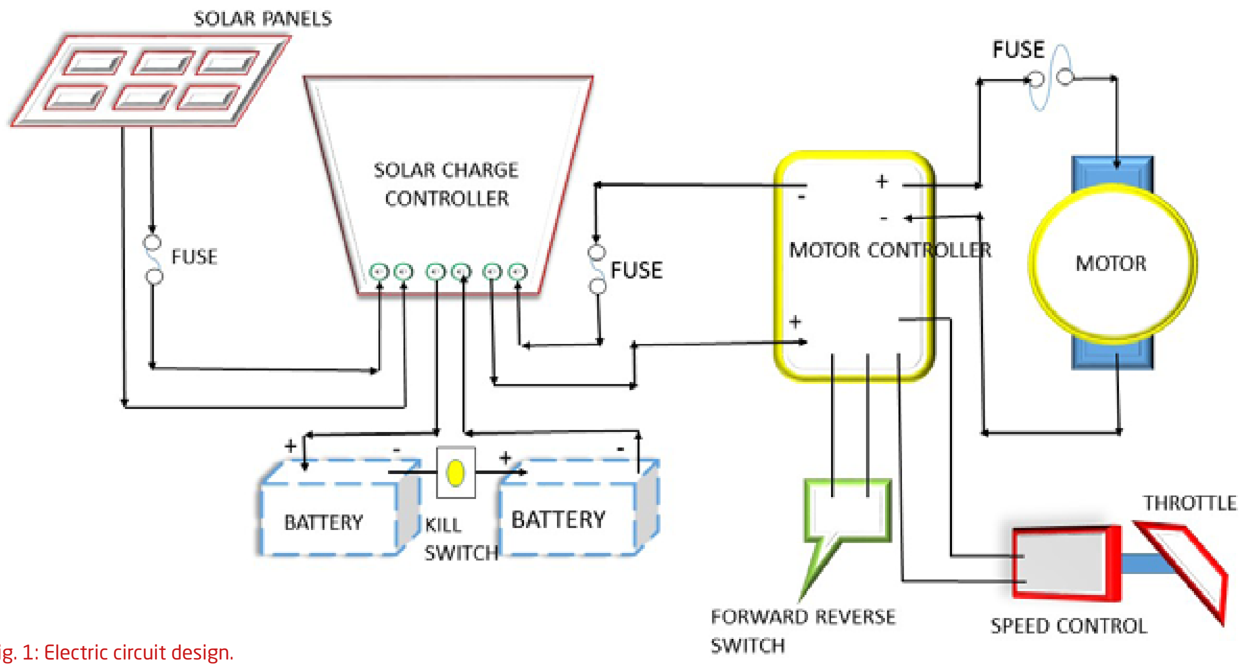

Fig. 1: Electric circuit design.

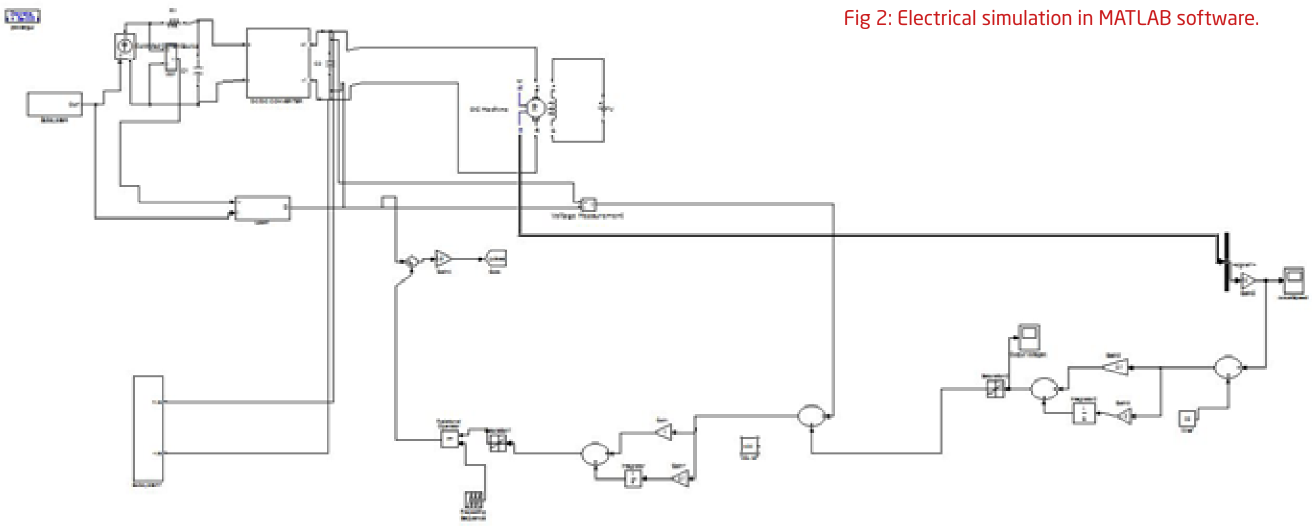

Fig 2: Electrical simulation in MATLAB software.

BLDC motor and motor controller (see Tab. 1). The wiring of all electric components should be done properly to ensure safety and for the ease of controlling them. The copper wires are suggested for the wiring as they have one of the highest electrical conductivity rates amongst metals and have high negative coefficient of temperature. In India wire selection is done using standard wire gauge (SWG) system. Since the max current flowing in the circuit is 40 A (considering starting current of the motor) selection of 25 mm^2 area of section of the copper wire is recommended.

MCB connections between components	Current capacity
Solar panel and solar charge controller	6 A
Battery and motor controller	10 A
Motor controller and motor	6 A

Tab. 1: Fuse or MCB ratings.

3 Simulation

The simulation is done in Simulink. Simulink is a software developed by Math Works. It is a graphical programming environment for modelling, simulating and analysing multidomain dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. The simulation describes the working of the vehicle. The aim of the simulation is to create the technical apparatus of every component that is utilised in the construction of the vehicle to show that the vehicle runs by using these apparatus in the physical world. All the parts including the solar panels, solar controller, batteries, motor and motor controller are created in the Simulink to study

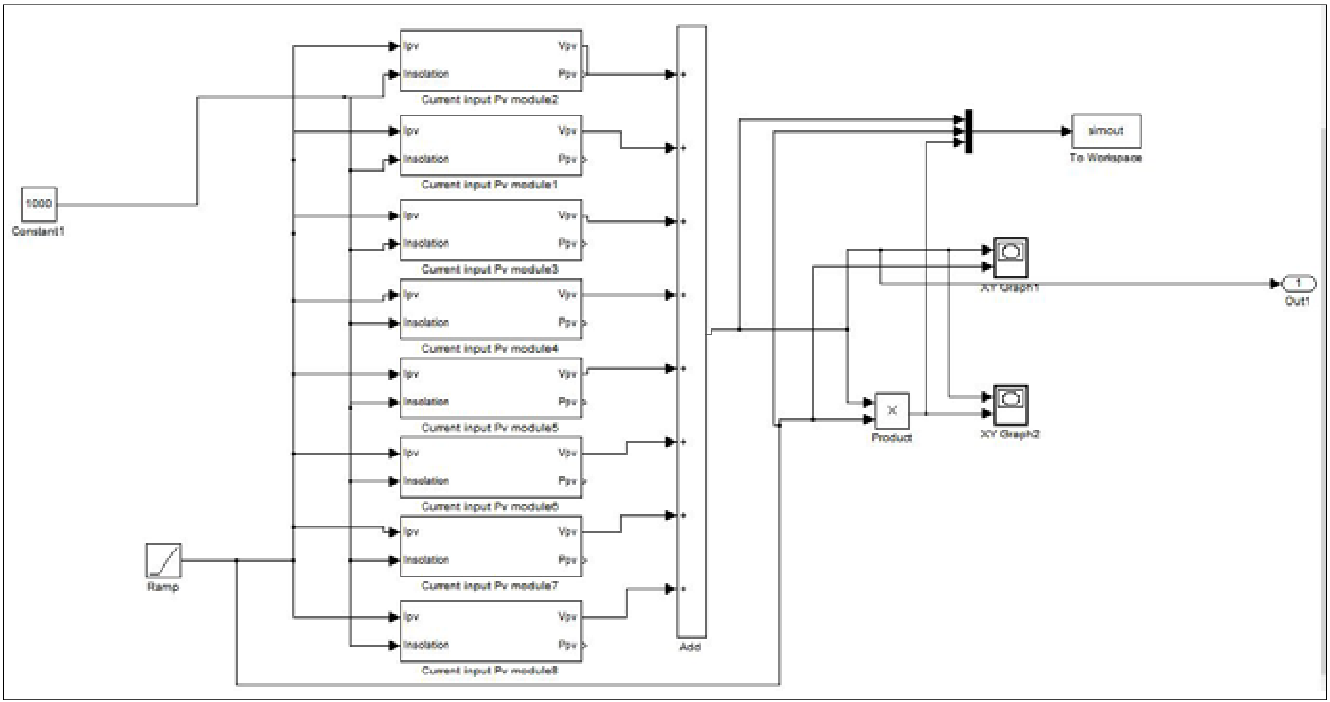

Fig. 3: Sub system of photo voltaic cell module.

their results in required conditions. The primary result of this simulation shows that the vehicle moves responding to the speed changes that are given during the acceleration. The secondary results like input power to the vehicle using the subsystems like solar panels and solar charge controller ("subsystem" block in fig.2) show the output of panels in physical world which is used as input power to charge the batteries. The complete feedback system gives the control flow in the motor controller.

The solar panels are designed in the Simulink with a capacity of 500 W. The capacity of the solar panels can be increased or decreased by addition or subtraction of the solar panel subsystems in the control system. The subsystem of photo voltaic cell is shown in the fig.3.

A constant input of 1000 and a ramp input of slope 6 are given as input to every solar panel module in the subsystem. The outputs of these subsystems are voltage (Vpv) of photo voltaic cell and power (Ppv) of photo voltaic cell. Functional block parameters of a single photo voltaic cell module is shown in fig.4.

All the outputs of the single photo voltaic cell are summed up to form the desired quantity. Photo voltaic cells are constant with respect to voltage so

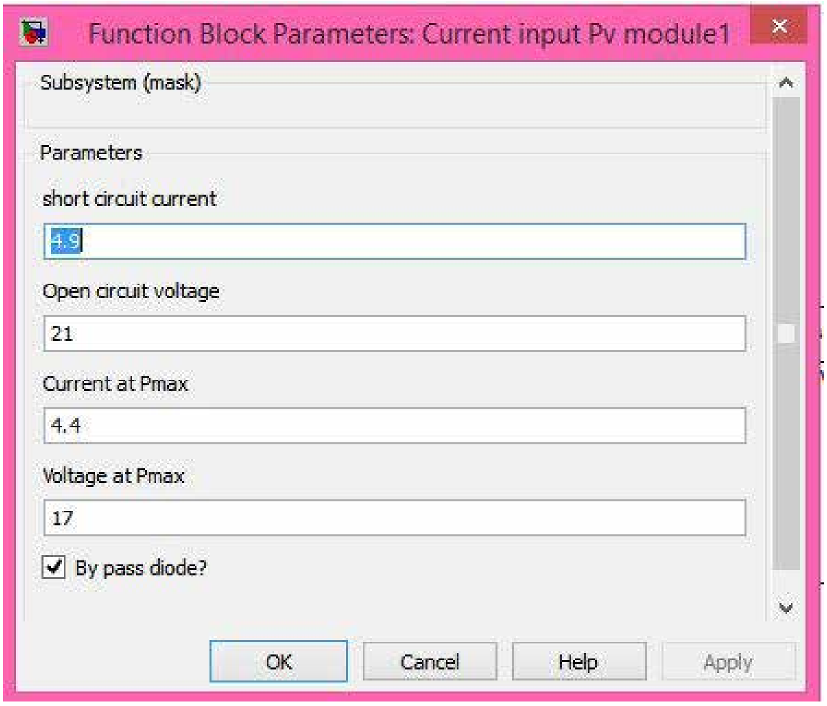

Fig. 4: Functional block parameter of a single Module.

the I-V characteristics and P-V characteristics of the photo voltaic cells are considered as the proof of proper functioning of the photo voltaic module in the sub system. Photo voltaic cell is a practical source. As every practical source has a drop due to the shunt resistance, the photo voltaic cells has a drop in both current and voltage. The results can be seen clearly considering the I-V characteristics and the P-V characteristics. The current has a drop due to the shunt resistance and the voltage has a drop due to the series resistance. These forms the I-V curve of the photo voltaic cells which are shown in the fig.5. Similarly once the voltage and current are known in the system, the power can be determined as the product of voltage and current through which P-V curves are obtained as shown in fig.6.

As physical quantities like sunlight, temperature, radiation etc. cannot be shown in MATLAB software, the photo voltaic cells also cannot be shown. Only if these curves are obtained, the sub system can be used as a photo voltaic cell in Simulink (MATLAB). Different curves are obtained for different positions of sun but it is essential for us to maintain at a point where maximum power can be derived. This is achieved from the maximum power point tracking (MPPT). There are many algorithms to implement the maximum power point tracking method. The algorithm used in this report is the perturb and observation method. This is the best control strategy for the MPPT technique. To know more about the perturb and observation method refer to the material mentioned in the reference [3]. Taking the voltage and current values from the photo voltaic cell, a MPPT with desired quality can be ordered. At the same time there is no requirement of any other converter as the load itself is dc (BLDC motor). If an ac motor is used, additional converter such as an inverter should be used to drive the motor. The power from the photo voltaic cells is not sufficient to run the motor so a dc to dc converter is to be used. It is also called as boost chopper or step up chopper. It is preferable to use a bidirectional chopper as we require to both step up as well as step down. A bidirectional dc to dc chopper is used to charge the batteries.

This acts as a step down chopper when charging the batteries and as a step up chopper when the batteries are discharging. If the maximum power point tracking method is used to switch on/off the chopper, we shall always be at maximum power point. In the chopper it is essential to use a MOSFET switch as this chopper works on low voltage and high frequency applications. The MOSFET switch is to be commanded on when to switch on/off as only on this command the circuit decides on voltage requirement. Finally, to control all these we require a closed loop controller. To control the dc motor, actual speed (fig.7) of the motor is considered. Then the reference speed fig. 8 (page 50) is given as an external input as the speed change due to acceleration is a physical quantity which cannot be expressed in the MATLAB software. From the comparison of these two speeds a duty cycle is obtained. Another duty cycle is taken from the MPPT. The average of these two duty cycles is used to switch on/off the dc to dc converter. Any change in speed is controlled through the chopper. The speed of response of the system is shown in the fig.9 (page 50). The comparison of both the actual speed as well as the reference speed is done and the error is fed to a PI controller. The PI controller corrects the duty cycle. Then the carrier voltage of the control system and the reference voltage (constant of 400 in this report) are compared and the resultant is fed to the chopper. Usu-

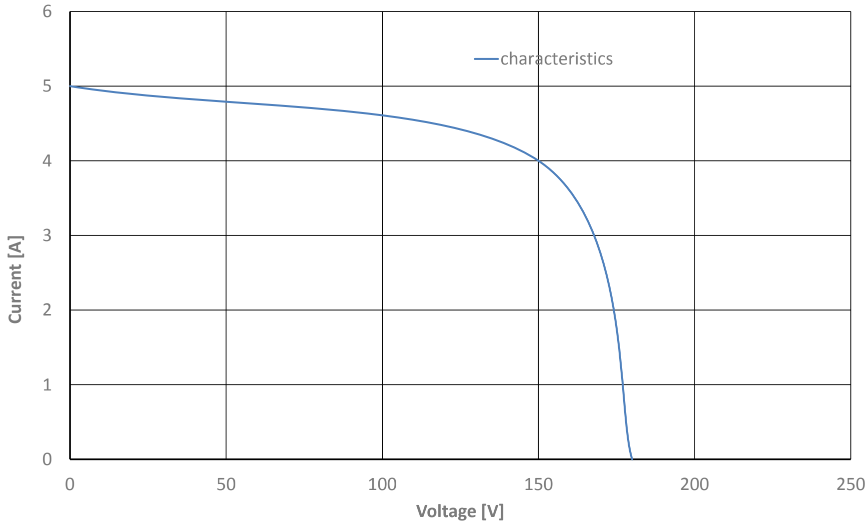

Fig. 5: Current-voltage characteristics of photo voltaic cell.

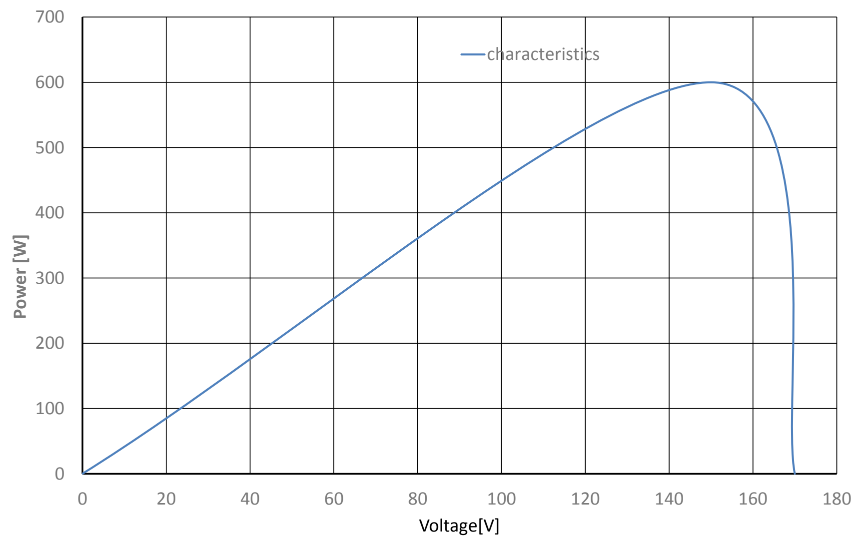

Fig. 6: Power-voltage characteristics of photo voltaic cell.

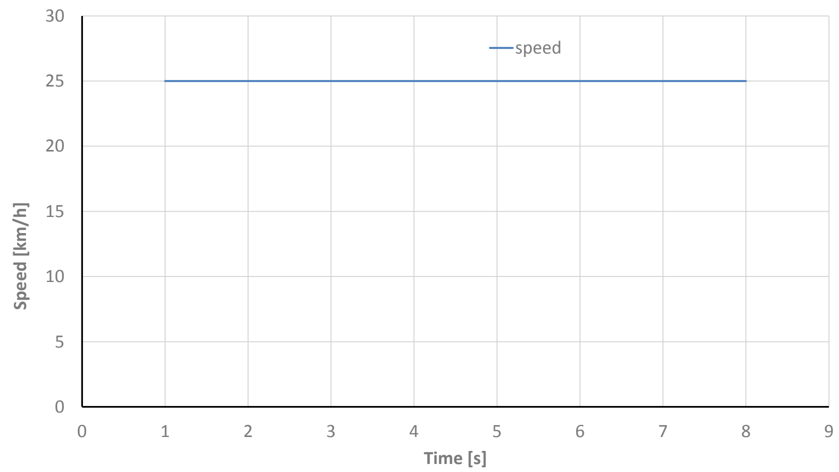

Fig. 7: Actual speed of the motor in speed vs time graph.

ally only a MPPT controller or a motor controller are used in one program in which individual duty cycles are considered but in this report both MPPT controller and motor controller are being used in a single program so the average of both the duty cycles must be fed into the chopper.

4 Selection process

4.1 Motor

Motor being a major device converting electrical energy into mechanical energy to bring the vehicle into motion, we need to consider important parameters in selecting the motor. Those are horsepower, efficiency, life, starting torque, speed, cost, size, weight and its characteristics under operating conditions.

According to the simulation, only DC motor gives the best possible results by giving fast responses to change in the speed of the vehicle using least number of converters. DC motor with mechanical torque as input is considered in the simulation. So, a DC motor which can give the required torque can be used for the construction of the vehicle. In this report, the selection of motor is also done considering the reduction of overall weight and cost of the vehicle.

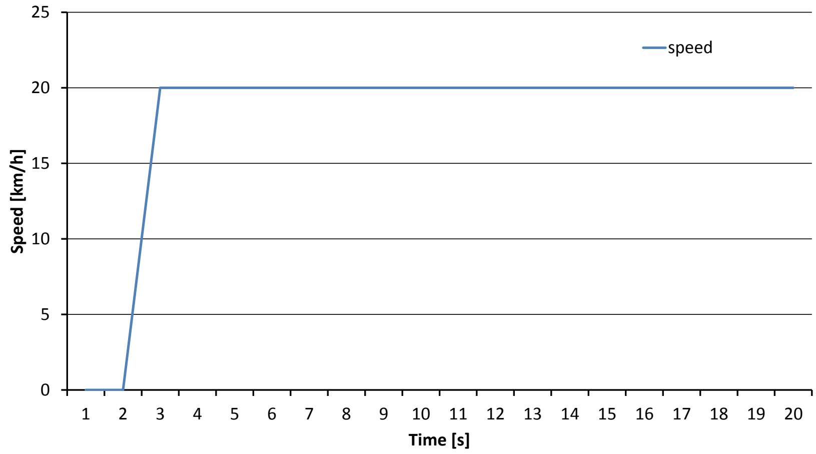

Fig. 8: Reference speed of 25 in speed vs time graph.

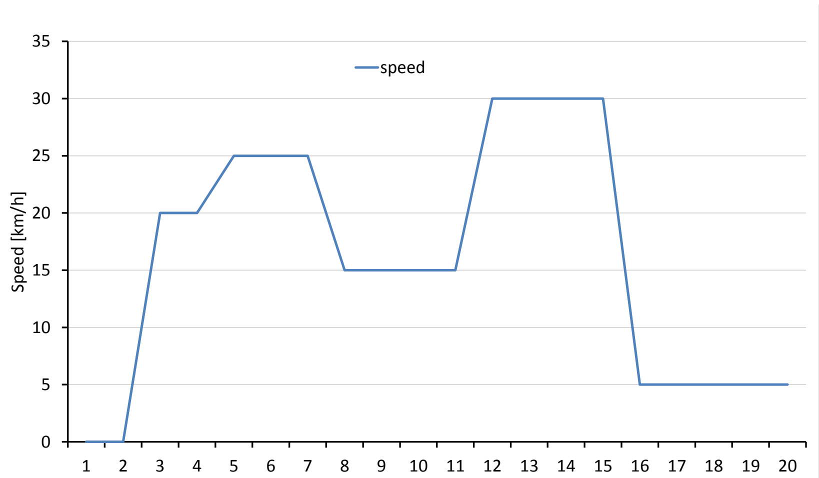

Fig. 9: Speed of response to change in speeds.

A brushless direct current motor is best suited for this type of vehicle. BLDC motor is a synchronous motorpower by a dc source through a switching power supply. The rotor of this motor is a permanent magnet synchronous motor. Although there are many technical details for the selection of BLDC motor to run the vehicle, a brief note of advantages are as follows while the others can be viewed through the references [7] [10].

- BLDC motor commutation is done based on rotor position information,
- high efficiency as voltage drop on electronic device is smaller than that on brushes,
- no maintenance as the brushes are absent,
- lower acoustic noises due to absence of arcs from the brushes to generate noise,
- greater dynamic response due to lower rotor inertia because of permanent magnets,
- smaller and lighter in weight,
- better speed vs torque characteristics as there is no brush friction to reduce useful torque,
- higher speed range as no mechanical limitation is offered by brushes or commutatotrs,
- better thermal performance as only the armature windings generate heat, which is the stator and is connected to the external part of BLDC motor
- longer life.

Due to the above mentioned advantages the BLDC motor is recommended in this report. The mechanical force required to move the vehicle and the force required to move the wheel can be revied from the references [6] [7]. Force required to move the wheel is generated from reference. Input electrical power is equal to sum of the output mechanical power and power losses due to copper winding in armature.

Field copper losses are neglected. A BLDC motor which can sustain a load torque of 25.4291 Nm (according to equation 3) should be considered for optimum results. So, a standard BLDC motor with ratings 48 V, 29 A, 32.92 Nm is considered. The mathematical calculations for the BLDC motor are as follows:

$$P_{electrical} = P_{mechanical} + P_{copper\ losses} \quad (1)$$

Where,

$P_{electrical}$ is input electrical power
$P_{mechanical}$ is output mechanical power
$P_{copper\ losses}$ is copper losses i.e. I^2R losses

$$P_{electrical} = V \cdot I \quad (2)$$

Where, V is supply voltage =48 V, I is current =29 A

$$P_{electrical} = 1392 \text{ W}$$

Load torque need to be calculated to know the amount of torque required to move the vehicle. It is also essential in selecting a perfect motor for the desired qualities.

$$T_{load} = F{\cdot}r{\cdot}\mu \qquad (3)$$

Where,
T_{load} is load torque
F is the force required to spin the wheel = 251.40 N (from force equation in reference [6])
R is the radius of the wheel = 0.2023 m
μ is the coefficient of friction = 0.5

$$T_{load} = 25.4291\ Nm$$

Considering the BLDC motor with torque greater than or equal to the load torque (T_{load}) with an output speed of 300 rpm and output torque of about 32.62 N · m.

$$P_{mechanical} = T_m \cdot \omega \qquad (4)$$

Where T_m is motor torque i.e. 32.62 N · m ω is angular velocity i.e. $\omega_{\omega rpm} \cdot (2\pi/60)$

$$P_{electrical} = 1024.268\ W$$
$$P_{copper\ losses} = I^2{\cdot}R \qquad (5)$$
$$P_{copper\ losses} = 116.899\ W$$

Therefore efficiency η

$$\eta = \frac{P_{mechanical} + P_{copper\ losses}}{P_{electrical}} \cdot 100$$

$$= 81.98\ \% \qquad (6)$$

Tab. 2 shows the technical specifications of the BLDC motor, fig. 10 a photo of the motor. As this report concentrates on eco-friendly solar vehicle, the requirement of speed is given the least priority.

4.2 Motor controller

The closed loop system made in the simulation works as a motor controller. Motor controller is nothing but a closed loop system which is used to control the motor speeds, current flowing through the motor, switching on/off the chopper through MPPT control and auxiliaries. The motor controller is designed especially for the motor used in the construction of the vehicle. The motor controller is custom made by a company after giving the detailed functioning of the system. A detailed picture of a motor controller is given in fig.11. Motor controller is an electronic circuitry which controls the speed of the motor by increasing/decreasing the potentiometer. Demagnetization of permanent magnets can be prevented by controller by avoiding overloading conditions.

Horse Power (1hp=745.69 W)	1 hp
Operating voltage	48 V
Operating current	15.62 A
Starting /max current	29 A
Maximum torque	32.62 N · m
Maximum output speed	300 rpm

Tab. 2: Technical specifications of BLDC motor.

Fig. 10: BLDC motor with chain drive.

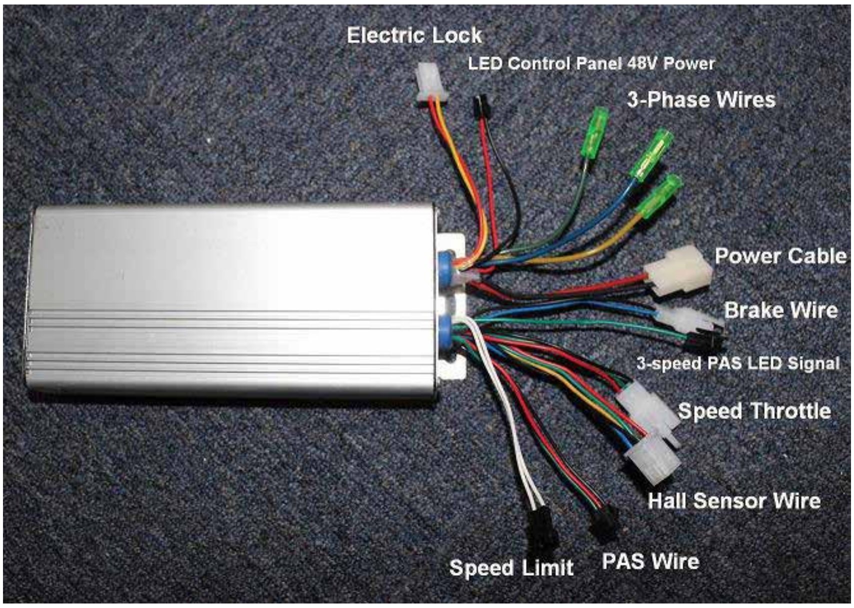

Fig. 11: Motor controller.

4.3 Solar panels

According to the simulation, to get the total power of 500 W, two solar panels of 250 W are connected in series (see Tab. 3 for specifications and dimensions). In this way solar panels can give the required amount of power to charge the batteries. In this report, the decision on selection of solar panels is done considering the ratings of the panels, area of the panels, cost and weight of the panels. Solar panels are the main source of power supply for the vehicle. The main function of the solar panels is that it should convert all the solar energy to electrical energy and then it is stored in the batteries which can be furthered used.. There are three types of solar panels which can be considered. They are mono crystalline, poly crystalline and thin films. The polycrystalline are manufactured easily by allowing liquid silicon to cool using a seed crystal of the desired crystalline structure other methods include chemical vapour disposition (CVD). We prefer these over other due to their high efficiency and low cost and maintenance. These panels are used for the solar car because of the lower heat tolerance but these panels occupy a bit larger space which can be further overcome by typical arrangement of the panels in a particular area. So, the polycrystalline are best suited for the solar vehicle as they are of less weight, lower cost and more efficient. In this report two panels of 250 W each connected in series are considered for installing exactly on the vehicle top.

Power	250 W
Rated voltage	30.2 V
Rated current	8.3 A
Voc	37.4 V
Isc	8.86 A
Tolerance	±5 %
η	15.1 %
Length	100 cm
Width	60 cm
Thickness	3 cm
Number of cells	9*6=54
Total area	6000 cm^2

Tab. 3: Specifications and dimensions of the panels.

Highly efficient solar energy practically does not depend only on the amount of heat or radiation falling on the panels but a combination of these along with the atmospheric temperature and regular cleaning of the panels helps in efficient excitation of the silicon molecules which is the primary cause for the generation of current.

4.4 Solar charge controller

The MPPT technique used in the simulation forms the solar charge controller in the physical world. The specifications of the solar charge controller are considered according to its efficient working during the simulation which are for an operating current of 40 A and an operating voltage of 48 V. Solar charge controller is considered for the need to control the power from solar to battery and to increase efficiency of the power being tracked by controller from solar panel without any power losses. Solar charge controllers are available in plenty in the open market but they should be selected wisely according to the solar panel ratings and the operating current. Solar charge controller is a small box consisting of solid state circuitry which is placed between a solar panel and a battery. Its function is to regulate the amount of charge coming from the solar panel that flows into battery bank in order to avoid the batteries being overcharged. It can also provide a direct connection to the load. There are two types of solar charge controllers. They are pulse width modulator (PWM) solar charge controller and maximum power point tracking (MPPT) solar charge controller. The later forces solar panel module to operate close to maximum power point to draw maximum available power. It also allows the use of solar panel module with higher output voltage than operating voltage of the battery which is not quite an advantage in a solar vehicle as there is no often change of solar panels once they are installed, keeping in mind the long life time of a solar panel (approx. 20 years). The use of MPPT solar charge controller reduces the complexity of connections which is also not a clear advantage as a maximum of two connections in excess to the present is required which does not sum up to be a great complexity. Although the use of MPPT solar charge controller is debatable for use in a solar vehicle due to its limited advantages and higher cost, it is preferable to opt for any of the two solar charge controllers depending upon the individual requirements. In this report, the MPPT solar charge controller is considered with 48 V and 40 A.

4.5 Batteries

Batteries form the main source of power from the solar panels to run the BLDC motor. In the simulation a battery which can be recharged with the help of solar power is designed. So, a battery must satisfy the property of charging and discharging which is considered in the simulation. When battery is in charging mode electrical energy is converted into chemical energy and while in discharging mode chemical energy is converted into electrical energy. The selection of batteries in this report is done considering the need to supply sufficient power to the motor, cost and weight of the batteries. There are two types of batteries which can be chosen to run the vehicle. They are lead acid batteries and lithium ion (cobalt) batteries.

In this report, the lithium ion batteries are considered due to the long discharging time, less weight and low maintenance. The main disadvantage of lead acid batteries are heavier (weight) than the lithium ion batteries and they require regular maintenance. In this report four lithium ion batteries of 12 V and 33 Ah are considered which are connected in series to achieve a total of 48 V and 33 Ah. The calculations on charging time and discharging time are the most important in perfect analysing of the working of the solar vehicle. The calculations are based on the specifications of motor, load torque, solar panels and batteries.

Capacity of the batteries = 33 Ah
Current from the solar panels (average) = 8.3 A

Charging time of the batteries = capacity in Ah/Charge rate in A (9)

Therefore, charging time = 33Ah/8.3A = 3.974 h.
The time mentioned above is the suitable considering only the ideal conditions. In practical the lithium ion batteries has an efficiency of 90 %. Considering the practical conditions:

Charging time of the batteries = capacity in Ah/(Efficiency · Charge rate in A) (10)

Therefore, charging time = 33Ah/(0.9· 8.3A) = 4.417 h.

Discharging time = (Capacity · Battery voltage)/Applied load (11)

Considering the motor uses an average continuous current of 15.62 A during the running of the vehicle, the applied load on the vehicle becomes 749.76 W.

Therefore, discharging time = (33Ah·48V) /749.76 W= 2.11 h.

This implies that when the vehicle runs at an average speed of 50 km/h the distance travelled by the vehicle turns out to be 50 · 2.11 = 105.5 km.

Assuming that the conditions are ideal for efficient charging of the batteries through the solar panels, the batteries get totally discharged within 2.11 hours, 47.76 % of the battery gets charged back according to equation (12). Due to which the vehicle can run for additional fifty kilometres.

Percentage of charging = (time for charging / total time for full charge) · 100 (12)

Therefore, percentage of charging = (2.11h/4.417h)*100 = 47.76 %

For one full charge, if the vehicle runs at a constant speed of 50 km/h, the vehicle runs a distance of 105.5 km. Similarly, at 47.76 % of full charge and at the same constant speed, the vehicle runs an additional distance of (0.4776*105.5 km = 50.38 km.

In the same way according to equation (12) while the vehicle runs an additional distance of 50.38 km, about 22.81 % of the battery recharges which can run for 24.06 kms more. Similarly, during the run of 24.06 km, about 10.89 % of the battery recharges and can run for extra 11.48 km. The next stages can be neglected as the batteries get completely drained of charge.

Therefore the total distance covered by the vehicle at a constant speed of 50 km/h in ideal conditions for efficient charging of batteries is (105.5+50.38+24.06+11.48) km = 191.42 km.

Mechanical Properties	Value
Density	2700 kg/m^3
Hardness (Brinell)	42
Ultimate Tensile Strength	152 MPa
Tensile Yield Strength	90 MPa
Elongation at Break	20 %
Modulus of Elasticity	69 GPa
Poisson’s Ratio	0.33
Melting Point	616-654 °C

Tab. 4: Mechanical properties of Al-6063-T1.

4.6 Materials

In this report, selection of different materials for the chassis and body works is done considering the physical properties of some selected materials. A right material is of utmost importance when it comes to designing a chassis because if a material of correct requirement is not chosen, the chassis could break on loads leading to fatal conditions of the driver. The following are the important considerations for the selection of proper material for the chassis. The material must have high yield strength, high machinability, easy weld ability, low cost, light weight and high elongation at failure.

Some of the materials under consideration include AISI 4130 (DIN 1.7218) chromyl steel (preannealed), AISI 1020 (DIN 1.0402) steel and Al-6063-T1. The problem with AISI 4130 (DIN 1.7218) steel was even though it gave good strength and lighter than mild steel (MS), it is expensive and not easily weldable. Welding AISI 4130 (DIN 1.7218) steel is not only costly but could not be trusted as it has to be annealed before and after welding yet gives fractures without notice. AISI 1020 (DIN 1.0402) steel is cheap, easily available and weld able and with some decent specifications but when analysed for chassis and various components like rear axle, etc., it showed a high deflection of 2 - 9 mm with very less factor of safety and addition of members to improve strength makes the chassis heavy. Aluminium alloy 6063-T1 gives enough yield strength to withstand all subjected stresses and loads. Though expensive, we cannot compromise on the quality on material for chassis and it is advised to look for a competitive price. Thus, Al-6063 satisfies all other requirements (see also Tab. 4).

Body Works is an important part of the vehicle design. External appearance is an important feature which not only gives grace and lustre to the vehicle but also dominates sale and marketing of it. Each product has a defined purpose. It has to perform specific functions to the satisfaction of customer. The functional requirement brings products and people together. However, when there are a number of products in the market having the same qualities of efficiency, durability and cost, the customer is attracted towards the most appealing and economical product. Three materials such as aluminium, carbon fibre and glass fibre can be considered for aesthetic considerations of the design.

Aluminium shows good properties like light weight, does not rust easily, and has good machinability but is costlier than steel and is very abrasive. Carbon fibre contains some ideal qualities like high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion. However, they are relatively expensive when compared to similar fibres, such as glass fibres or plastic fibres. Thus, budget exceeded in its place. Glass fibre is light weight, easily mouldable, easy machining, fire resistant, low maintenance, anti-magnetic, good electrical insulator. However, it is costlier than aluminium but fits into economic range. Selection of glass fibre as the material for moulding the body of the vehicle is an educated choice since glass fibre is cost effective, light weight, has good strength, it fits into the requirement slot for manufacturing the solar vehicle.

Fig. 12: Body of the solar vehicle.

4.7 Braking system

Braking system makes an important mechanical entity to any automobile. An excellent braking system is the most important safety feature of any land vehicle. The main requirement of the vehicle's braking system is that it must be capable of locking all wheels on a dry surface. Ease of manufacturability, performance and simplicity are a few important criteria that are to be considered for the selection of the braking system. The two main types of braking systems under consideration in this report are drum and disc brakes. In case of drum braking there is a high possibility of mud and debris to gather in the space between the shoe and the drum. Same problem is faced in mechanical disc brakes, but not in hydraulic disc brakes. Hydraulic brakes are found to be suitable for all type of terrain. Since, drum brakes are of more cost and they are heavier in weight which greatly increases the weight of solar car we can eliminate it. On the other hand, using hydraulic brakes can be an asset as it is cheap and it is readily available. But the drawback was using this system the overall weight of the solar car is increased which makes it harder for the motor (linked to battery to solar panels) to run the car. The discs of brakes are made of paralytic grey cast iron. The material is cheap and has good anti-wear properties. Cast steel discs have also been employed in some cases, which wear even less and provide higher coefficient of friction; yet the big drawback in its case is the less uniform frictional behaviour. Two types of discs have been employed in various makes of disc brakes, i.e. the solid or the ventilated type. Disadvantages of ventilated type discs include usual thickness and heavier than solid discs. In case of severe braking conditions, they are liable to wrap, accumulation of dirt in the vents, which affects cooling, resulting in wheel imbalance. Turning produces vibrations which reduces the life of the disc. Any of these make no much difference on the solar vehicle mentioned in this report as its overweight cannot go beyond 450 kg to 500 kg. Although in the practical version of the solar vehicle done through this report hydraulic drum brakes are used for the front axle and mechanical disc brakes are used for rear axle for experimentation (fig. 13). It is advisable to opt for hydraulic disc brakes for both the front and back axles as they are economical and reliable.

Fig. 13: Experimental braking system used in vehicle.

4.8 Steering system

The controlling behaviour of a vehicle is influenced by the performance of its steering system. The track consisting of sharp turns and the stability of the system and the response time (feedback) are vital factors in deciding the vehicles' run. The worm and sector mechanism, rack and pinion and the re-circulating ball mechanism were among our options to go with. In this report, on consideration of mounting ease, simplicity in design and considering that our vehicle is of the compact category; rack and pinion is chosen over the others. A practical picture is shown in the fig.14. The rack and pinion being a simple system; can be easily manoeuvred and the defect, if any, can be spotted and taken care of. Moreover the steering wheel and other relevant apparatus are so placed in the design, for easy entering and exit of the driver. Rack and pinion steering gear being compact and light package with kinematically stiffer characteristics commonly employed on passenger vehicle cars. The composite error in the gear increases the torque required to rotate the steering wheel by the driver. Rack and pinion steering system has a very few moving parts, lighter in weight and economical. It converts the rotational motion of the steering wheel into the linear motion needed to turn the wheels. It provides a gear reduction, making it easier to turn the wheels. Recirculating steering system is used in heavy vehicle but for solar car the rack and pinion would be

Day	Battery (Ah)	Current (A)	Charging time (h)	Efficiency (%)	Actual time (h)	Current drawn (A)	Load (W)	Dischar-ging time (h)	Speed (km/h)	Distance (km)*
1	33	8.34	3.956	90	4.396	15.62	749.76	2.112	50	105.6
2	33	8.24	4.004	90	4.449	17.78	853.44	1.856	50	92.8
3	33	8.1	4.074	90	4.526	16.24	779.52	2.032	50	101.6
4	33	8.15	4.049	90	4.498	15.40	739.20	2.142	50	107.1
5	33	8.32	3.966	90	4.407	15.33	735.84	2.152	50	107.6

Tab. 5: Speed, distance covered and time taken for charging and discharging.

the good choice. In this steering system we can change the steering ratio according to our desire like 12:1, 7:1, 10:1 etc. which will really increase the efficiency of our solar car.

4.9 Chain drive

Chain drive is a way of transmitting the mechanical power from one place to another. It is often used to convey power to the wheels of a vehicle, particularly bicycles and motorcycles. It is also used in a wide variety of machines besides vehicles. Most often, the power is conveyed by a roller chain, known as the drive chain, passing over a sprocket gear, with the teeth of the gear meshing with the holes in the links of the chain. The gear is turned, and this pulls the chain putting mechanical force into the system. Idler wheel are gears that do not put power into the system or transmit it out. An idler-wheel drive is a system used to transmit the rotation of the main shaft of a motor to another rotating device. An idler gear is a gear wheel that is inserted between two or more other gear wheels. The most important point to be noted in chain drive system is that the motor gear and the rear axle gear must be on a same line perpendicular to the rear axle. Any small error will result in displacement of chain. In this report, it is suggested to use a 2:1 ratio for teeth at the gears near the motor and at the rear axle.

There is a chance of flexibility in chain drive system. If the individual requirement is to go for faster speeds then the same ratio as mentioned earlier must be followed with more teeth at the motor and less number of teeth at the rear axle. If the individual requirement is for higher torque due to hilly or sandy roads, the same ratio in reverse must be followed

Fig. 14: Rack and pinion steering system.

with more teeth at the rear axle and less number of teeth are the motor gear.

5 Experiences

We tested the vehicle quite a few times and each test made us know much more interesting things about it. Initially, we couldn't reach our estimated power and distance but some changes to the design and distribution of apparatus made it efficient. Some of the major problems we faced are mentioned in brief.

One major change which turned the tide was the introduction of chain drive system replacing the former belt driven system. The rubber belt was used to connect the motor shaft and the rear axle with the help of a pulley. As the number of tests increased, the belt began to expand due to the heat produced due to the friction between the motor shaft and the belt. This led to increased power consumption by motor which led to fast discharge of batteries. Also the belt had to be tightened by changing the position of motor which is a tedious job. The chain drive system answered all the queries of the previous system by decreasing friction, no requirement to displace motor, decreasing discharge and no jerk movements or slipping of the belt due to initial start-up.

The selection of a reliable braking system is a very important part of achieving proper vehicle control. We started with disc brakes for both front and rear axles. The front axle brakes are making the design of the steering system complex and it had to be replaced. So, they were changed to drum brakes which are placed inside the tyre rim by giving us proper space for the steering. We also replaced the rear brakes with drum brakes but due to lack of professional knowledge on this kind of complex braking, we could not achieve reliable braking. This had a drastic effect on the morale of the group as it resulted in an accident breaking the entire rear axle into half. Finally, we settled the problem by the use of mechanical disc brakes to rear axle which are mounted on the rear axle beside the pulley. It had a simple operation and selection of proper disc brake helped us by achieving efficient braking.

Some practical changes include placing the thermocouple sheets under solar panels and metal apparatus to damp the sound created during the vehicle run. Using a better insulated wiring in place of regular wires to withstand the heat produced by the high current flow. Distributing the weight of the apparatus innovatively by not clustering all the parts of a specific apparatus at a single place.

Every change made up learn more about the vehicle dynamics and helped in achieving the desired result. Some of the test drive results are tabled in Tab.5. Actual time is calculated by considering the efficiency of the batteries [battery capacity in Ah / (efficiency · current). The current drawn is observed by the use of a DMM (Digital Multimeter) during the vehicle run. It is not practically possible to run the vehicle at 50 km/h for such a long time. So, the vehicle is made to run in the range of 40 km/h to 60 km/h and the average of the speeds is considered for calculations. The starting speeds till 40 km/h is achieved in a very short time so they can be ignored.

6 Discussions

In extension to this model of solar vehicle, there is scope for developments and also discussing some practical problems.

The introduction of regenerative braking to the existing model can be of a significant boost to the solar vehicle. As for every time the brakes are used, it helps in charging the batteries. This decreases the pressure on the solar panels to charge the batteries and the batteries can be charged quicker than at present. When you're driving along, energy flows from the batteries to the motors, turning the wheels and providing you with the kinetic energy you need to move. When you stop and hit the brakes, the whole process goes into reverse: electronic circuits cut the power to the motors. Now, your kinetic energy and momentum makes the wheels turn the motors, so the motors work like generators and start producing electricity instead of consuming it. Power flows back from these motor to the batteries, charging them up. So a proportion of the energy you lose by braking is returned to the batteries and can be reused when you start off again.

A solar tracking system along with the MPPT solar charge controller can be an effective addition to the present technology. As the sunlight can be in various direction other than the way the vehicle is running or the radiation might be falling slant on the panel, the solar tracking device can track the sunlight and position the panel perpendicular to the radiation and get maximum output. This helps in higher current to charge the batteries faster. A combination of both the above mentioned techniques would be a great boost to the available technology as proposed in this report.

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