Cars that Run on Sunshine

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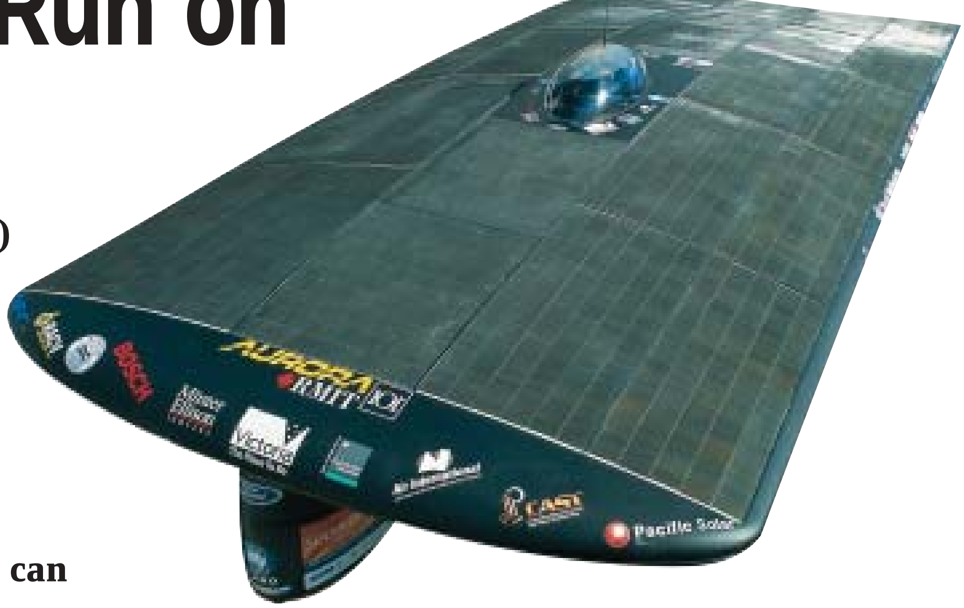


Aurora solar car

Automobiles, the most common means of transportation, are presently responsible for about 20 per cent of global energy consumption. Limited global petroleum reserves are being depleted at a rapid rate. If current levels of fuel consumption continue, the remaining supply of petroleum may be depleted in less than fifty years.

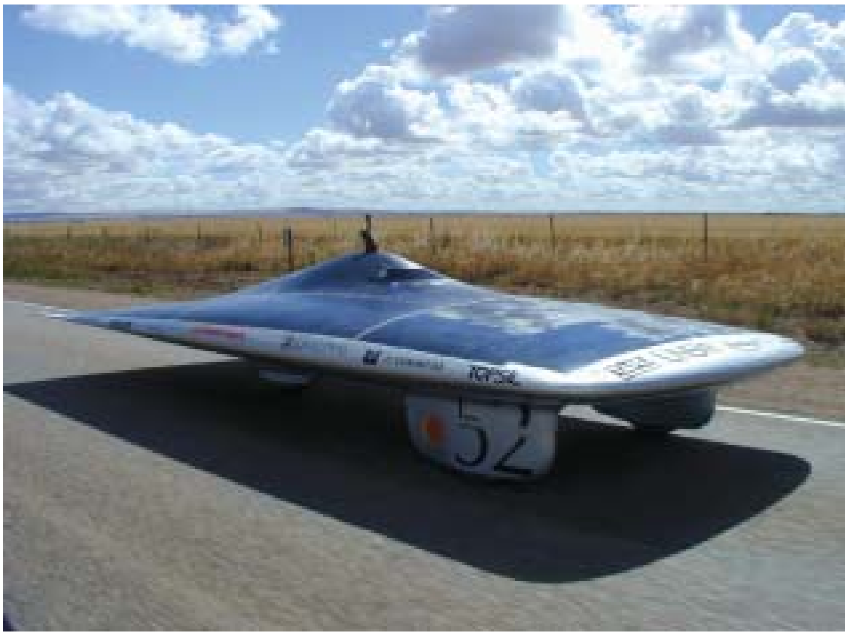
Cars today contribute anywhere from 60 to 90 per cent of the air pollution in urban areas. Every gallon of petrol that a car uses produces 22 pounds of carbon dioxide, which in turn adds to the greenhouse effect and other hazards such as air pollution. Although technology has succeeded in achieving a drastic reduction in tailpipe emissions, the number of cars on the roads has dramatically increased in recent years. The total air pollution from tail emissions continues to be a cause for concern.

These problems have forced the automobile industry to consider alternative fuel vehicles (AFVs). An AFV is a vehicle that relies on energy other than gasoline, with zero or low emission. Vehicles powered by solar and other renewable energy sources are possible alternatives to conventional vehicles powered by internal combustion engines and fossil fuels. Developed countries and automobile manufacturers have been investing money, time and manpower into the research of AFVs in order to satisfy both consumer demands and environmental regulations. Consequently, research has lead to significant development of solar-powered cars (SPCs). SPCs use solar energy to either power an electric motor directly, and/or use solar energy to charge a battery, which powers the motor. The motor, in turn, imparts motion to the automobile. Although SPCs have the potential to reduce harmful pollutants, they need further research to overcome the limitations that are preventing their widespread use in the near future.

Solar car concept

In order to evaluate the viability of solar vehicles, there is a need to understand the fundamental principles underlying the solar energy concept. SPCs incorporate an array of solar photovoltaic (PV) cells (or modules made of cells). The PV array is integrated or built onto the vehicle roof and body itself. Incident solar energy is converted into electricity by the PV array. This electric energy is stored in batteries. Solar electricity can also be directly fed to an electric motor powering the vehicle. Electronic motor controllers facilitate smooth and efficient control of requisite power to the motor. Speed control is performed by the normal car accelerator pedal. A recent motor technology uses powerful rare-earth magnets, with a brushless design. A 5 HP motor weighs less than 5 kg. Gear changing is done electronically.

The convergence of emerging technologies—such as aerodynamics, declining-cost solar photovoltaic, power electronics, electronic control systems, materials science, batteries, simulation, and computerised design systems—has opened up new vistas for SPCs.



UNSW Sunswift II

Solar cells

The efficiency of solar PVs has been steadily increasing with technological improvements. Crystalline silicon modules, which are 'interconnected arrays of PV cells that generate enough electricity to be useful' are from 10 to 13 per cent efficient. Experimental PV silicon cells have achieved efficiencies of 24 per cent. The efficiency of these cells is important to compensate for the low concentration or intensity of solar energy. On an average, about 5 kilowatt hours of solar energy is incident on a flat level earth surface of one metre square. This averages to about 0.2 kW/metre square in a day. This intensity is relatively low, considering the fact that a 100 W light bulb has an intensity of 12 kW/metre square. Therefore, SPV energy systems need more area. This is a major problem, since space on a car is very limited.

Currently, SPCs are not capable of meeting the demands of automobile users. An all-solar-powered car is not a possibility at present, unless the efficiency of solar cells is greatly improved. Efforts are on to develop thin-film solar PV cells, which would be more economical to produce than creating silicon wafers.

Solar car design

Solar array: The solar PV array is the power plant of the SPC, converting sunlight into electricity to power the motor that drives the car. Not surprisingly, the efficiency of the solar PV panels is the most important factor for the solar array, as higher efficiency panels generate more power from a given amount of sunlight. A high-performance solar panel produces 200 W of power under full sunlight per square metre area and costs US$ 2000. A medium performance solar panel generates 150 W of power under full sunlight, but is less expensive, at US$ 900. Presently, a typical SPC design dedicates 8m^2 of area to the solar array. Therefore, a total of eight 1m^2 solar panels can be built into the car. Depending on the cost to be incurred, the proportion of high and medium performance solar panels can be used, and accordingly, the total power generated can be calculated from the combination of these solar panels.

General Motors has used gallium arsenide cells in its 'Sunracer' solar car. Gallium arsenide is more efficient, but is expensive.

Solar car body: Two options are available at present for choosing the body of the solar car. These include the 'composite cambered airfoil' and the 'tubular separate cab and panel'. The airfoil offers a superior body design from a performance standpoint, but is more expensive. It is better since it is lighter and has better aerodynamic features. Aerodynamic drag is an important aspect to be considered in the design of the solar car body. Aerodynamic drag is the resistance a SPC body experiences from the air as it is driven. Body designs with a higher aerodynamic drag suffer from a greater resistance to motion as compared to those with a lower aerodynamic drag. If a car has a higher coefficient of drag, it requires more power to move at the same speed as a car with lower coefficient of drag.

Plastic and Kevlar, used by the Dutch 'Nina' SPC, help in reducing the body weight to 220 kg. Advances in lightweight structural materials have contributed to improving solar car performance. The 'Sunracer' model has an alumunium chassis and body made of two lightweight composite materials.

Motor and transmission: The motor and transmission module constitutes the power train of the SPC. The motor converts electrical energy from the solar array and batteries to mechanical energy, which is then transmitted to the car wheel through the transmission system. There are two choices for the motor/transmission systems. These include the wheel motor (wherein the motor is incorporated inside on the wheels), and the DC brushless motor with chain and sprocket transmission system.

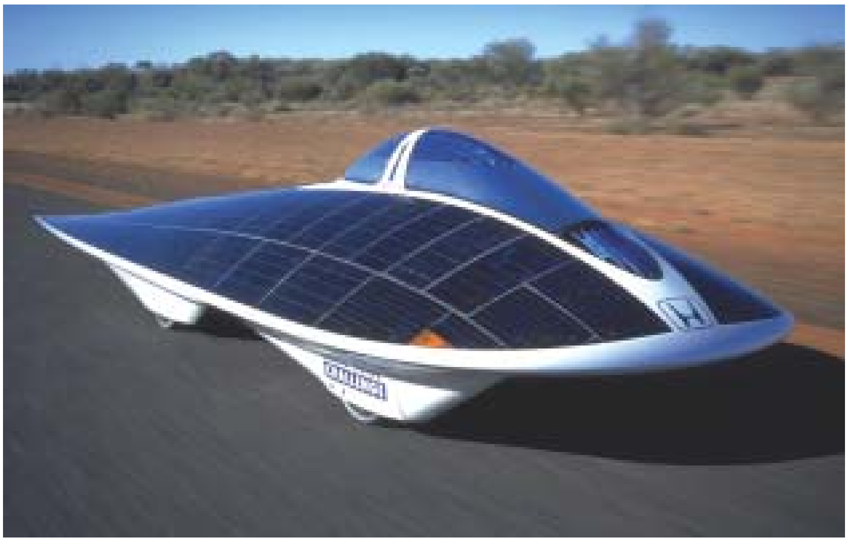
The efficiency and cost of the motor and transmission components are vital factors to be considered when choosing between the two. The wheel motor has excellent efficiency when operated at high power and low efficiency when operated at low power. The wheel motor does not have a proper transmission component to optimise its operating conditions for best efficiency. On the other hand, the DC brushless motor has a lower efficiency compared to the wheel motor at high power. But the chain and sprocket transmission system enables the DC motor to change its gear ratio easily. The DC motor has a higher efficiency compared to the wheel motor at lower power.

DC brushless motors have an efficiency of 94 to 99 per cent. Direct drive system eliminates drive-train losses. The motor, if fitted in the wheel, reduces aerodynamic drive and offers maximum efficiency.

The motor, fitted in the front wheel, facilitates simple steering without upsetting the car stability at high speed. The motor structure forms a ring, with permanent magnet excitation for low losses. The geometrical arrangement features an axial flux, ironless air-gap winding, and outer rotating magnets. Eddy current, copper, winding, and bearing are the sources of loss in the motor. Litz wire, with twisted, transposed strands, can be used to reduce circulating currents and eddy current loss.

A rare earth magnet solar car wheel motor, designed for the Aurora solar car, fits completely inside the car's front wheel. It has an efficiency of 98 per cent at 1500 W.

In general, to deliver power to the wheels, three basic types of transmission systems are used. These include single reduction direct drive, variable ratio belt drive and hub motor. Single reduction direct drive transmission systems are reliable, easy to maintain, and, if designed well, can result in efficiencies of over 75 per cent. Variable belt drives can adjust the gear ratio as the speed changes and so provide high-starting torque and high cruising efficiencies. These drives require precise construction. The newest idea is the hub motor, with an efficiency of over 95 per cent.



The two seat Honda Dream in the 1996 World Solar Challenge

Maximum power point tracker: The maximum power point tracker is a device that maximises the power output from the solar level. The solar array generates steady voltage. However, the current will vary depending on the level of exposure to sunlight. The maximum power point tracker samples values of the current and then adjusts its impedance to maintain the level of current so that it falls within the range of maximum power generation. The motor controller is the interface between the accelerator and the motor.

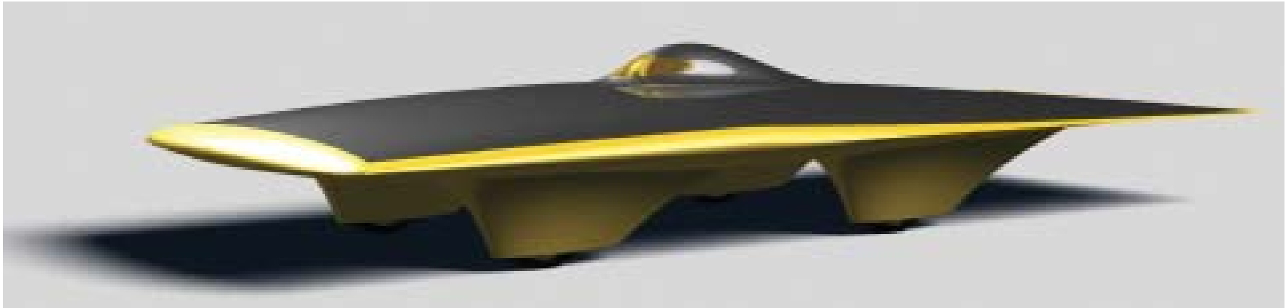
The energy from the solar PV cells is fed to maximum power point trackers, which vary the load to get the maximum power. The power point trackers can take the form of DC-DC converters and are available in two forms. Boost trackers raise the voltage to the battery voltage while power point trackers lower it. Boost trackers are considered better as the cells can still be connected to the battery to charge it if the power point tracker fails.

Motor controllers or the solar car brain: Motor controllers are frequently referred to as the 'brains' of a solar car. This component performs the complex task of deciding how much current actually reaches the motor at a given time. This determination of current by the motor controller allows the car to accelerate, decelerate, or stay at a constant speed.

The first motor controller used by a solar car built at MIT, USA, was simply a knife switch. A knife switch is only able to switch between two voltages, namely, the voltage of the battery and the ground. In fact, this was a standard DC motor controller. The idea was that when the car is to be accelerated by pressing an accelerator padel, the motor controller would turn the switch on between the battery and motor, allowing full current to reach the motor. Subsequently, PWM (pulse width modulating) motor controllers and motor torque controllers were developed.

Newer motor controllers consist of two finite state machines. One finite state machine performs the chopping effect—the switching on and off process. The other finite machine performs commutation, a six-step process that delivers how much and in what direction current is to be delivered to the motor.

Batteries: Batteries are essential for solar cars. They are needed for storing extra electrical energy for later use in cloudy conditions, for overtaking other cars on the road, and for an extra boost when climbing hills. The batteries store energy from the solar array, making these available for



High-Resolution rendering of SunTiger V solar car of the University of Missouri

use by the motor. Battery components include lead acid, nickel metal hydride (NiMH), sodium sulphur, lithium metal disulfide, sodium nickel chloride, lithium-ion, nickel zinc, silver zinc and lithium-ion polymer prismatic cells.

Lithium polymer and zinc bromine batteries have energy densities in the range of 200 Wh/kg, far greater than 40 to 50 Wh/kg for lead acid batteries.

Tyres and suspension: Rolling resistance and cost are the two most important factors relating to the tyres and suspension of SPCs. Rolling resistance is the resistance of the car to rolling due to the adhesion and deformation of the tyres when they make contact with the road surface. A wide underinflated tyre, with a very large area of contact with the road, will have a much higher rolling resistance compared to a narrow, fully inflated tyre. A SPC with a higher coefficient of resistance requires more power to race at the same speed as a car with lower coefficient of rolling resistance. Magnesium alloy rims offer great strength.

Differences with conventional vehicles

There are fundamental differences in the structural and functional requirements of cars powered by internal combustion (IC) and those powered by solar cells. SPCs are powered by small, highly efficient, brushless DC motors built into each of the back wheels or front wheels. In IC vehicles, the space below the floor is required for the drive shaft, exhaust pipe, and muffler, none of which are necessary for SPCs. SPCs, on the other hand, use this below floor space for a battery-built-in frame, which holds the batteries, keeping the centre of gravity of the SPC low, thereby improving stability. The vehicle's roof is fitted with solar panels.

Research and testing

Major automobile companies are engaged in constant research and testing programmes to improve performance of SPCs. Efforts are on in R&D labs and projects to improve the efficiency and output of photovoltaic solar arrays. Composite teams from a wide range of technologies are feverishly working on means to improve solar car body architecture, aerodynamic design, solar PV panels, electric motors and transmissions, batteries, suspension and steering, brakes, wheels and tyres. The pace at which research activities are being pursued, it is predicted that commercially viable solar cars will roll out within a few years.