

Development of a Solar-Powered Racing Vehicle for Endurance Competition: Design, Fabrication, and Performance Targets

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Abstract This paper documents the design and fabrication of a solar-powered racing vehicle engineered to compete in the World Solar Challenge. The project was guided by three core engineering principles: minimizing mass, optimizing aerodynamic efficiency, and maximizing powertrain and energy system performance. This initiative serves as a practical exploration of renewable energy applications, particularly relevant in regions like the Arabian Gulf with abundant, year-round solar resources. Given the significant domestic consumption of fossil fuels for electricity generation and transportation, this project underscores the vital importance of developing and promoting alternative energy solutions. The vehicle's initial tested speed is 70 km/h, with a target performance of double that for the 3,000 km endurance race. Its chassis and body were constructed from lightweight aerospace-grade aluminum and fiberglass composites. The powertrain features custom-designed AC motors integrated with a specialized gearbox, steering assembly, and suspension system. The electrical system incorporates semi-flexible photovoltaic panels coupled with maximum power point trackers and comprehensive instrumentation. The final vehicle accommodates a single driver and has a net weight of 300 kg.

Keywords Solar Car Design, Solar Race Car, Solar Energy, World Solar Challenge

technology cars and working with environmental and advanced materials technology. These races are often sponsored by government or educational agencies, and businesses such as Toyota keen to promote renewable energy sources [1, 2, 3].

The cars require intensive support teams similar in size to professional motor racing teams. This is especially the case with the World Solar Challenge where sections of the race run through very remote country. The solar car will travel escorted by a small caravan of support cars. In a long distance race each solar car will be preceded by a lead car that can identify problems or obstacles ahead of the race car. Behind the solar car there will be a mission control vehicle from which the race pace is controlled [2]. Here tactical decisions are made based on information from the solar car and environmental information about the weather and terrain. Behind the mission control there might be one or more other vehicles carrying replacement drivers and maintenance support as well as supplies and camping equipment for the entire team [3].

Our eco-efficiency challenge allows teams to participate and demonstrate the sophistication and performance of solar-powered vehicle. The underlining mission of the solar challenge is to increase the number of people in Saudi Arabia that are interested in the Science, Technology, Engineering and Mathematics (STEM) subjects [3]. These subjects are crucial to get the country to a higher level. Next, it will give us a platform where we can exercise our skills in building cars locally. This in turn will result in an increased level of knowledge in the industry about electric motors, battery systems, vehicle aerodynamics and more. Finally, the solar cars will show the public what solar panels can do. If people see solar panels driving a car, you will have a positive sentiment to it. Being more positive to this technology will also make electric vehicles more acceptable to people. The Sasol Solar Challenge motivates student to fresh thinking, a creative approach, and flexible solutions.

1. Introduction

Solar Energy Cars

Corporate teams participate in the races to give their design teams experience of working with both alternative energy sources and advanced materials. University teams participate in order to give their students experience in designing high

Solar Energy in KSA

The construction boom and growing population of Saudi Arabia result in the rise of the country's electricity demand. The ongoing high loads require appropriate and adequate power generation. However, it is well known that conventional generation by means of fossil fuels is a chief cause of environmental pollution and impacts human health through emissions of harmful gases such as nitrogen oxides (NO , NO_2 & N_2O), sulfur oxides (SO_2 & SO_3), and carbon oxides (CO & CO_2). Therefore, it is essential to find an alternative way to support current conventional generation in Saudi Arabia that also preserves the environment and human health. Saudi Arabia is geographically strategic because it is located in the so-called Sun Belt, and it has widespread desert land and year-round clear skies, which have led it to become one of the largest solar photovoltaic (PV) energy producers. The average energy from the sunlight falling on Saudi Arabia is 2200 thermal kWh/m^2 , and it is therefore worthwhile to attempt to generate clean energy in the country via direct sunlight through PV cells [3].

Applications of solar energy in Saudi Arabia have been growing since 1960. A systematic major research and development work for the development of solar energy technologies was started by King Abdul-Aziz City for Science and Technology (KACST) in 1977. The Saudi Solar Radiation Atlas project was initiated in 1994 as a joint research and development project between the KACST Energy Research Institute and the US National Renewable Energy Laboratory [3]. The solar village project site is located 50 km northwest of Riyadh and supplied between 1 and 1.5 MWh of electric energy per day to three rural villages. It was the biggest project of its type in 1980 and cost \$18 million [10].

The scope of the research is about how to transfer solar energy into electrical energy through PV cells then inject it directly into the power transmission lines and thus this article does not mention about storage energy. However, some studies have mentioned it. The objective of such a project like that is we can have eco-friendly car's, also Fuel efficient and using the sun for power instead wasting it [10].

And it is important to Saudi Arabia because in 2005, Saudi Arabia was the world's 15th largest consumer of primary energy, we can save the oil that goes to transportation by using solar as alternative.

Solar Car Race

Solar cars project is a project that has many values for the advantages of the human beings especially when recognizing the importance of alternative energies. In somehow there are many benefits that solar car can offer to the environmental changes and the urgent need to oil and other kinds of energy. Because of the importance of transportation and the quality of its means in the world, it was great concern to think in

another means that help man with new design and new ideas. The solar car is not a new invention, but it is a way to think for different solution to help the country to avoid energy problems. This is because of the continual needs to a car; however, it is difficult to continue depending on oil which is expected to finish after few decades.

Using solar energy becomes very important in our daily life and for the purpose of industries. During last few years, all manufacturers were afraid of using most of alternative energies because of less experience and no complete guarantee to use one of that energy. In addition, solar energy is considered one of the cheapest energies to be used especially in the Arabian Peninsula. Technically, solar energy has specific tools which can be used in different electrical instruments and support electrical machines as well. Solar panels nowadays become available in the local markets in the Gulf where some factories in the Far East become professional to manufacture different kinds in different sizes. Chemically, there are some disadvantages of using solar panels with mechanical and electrical systems which may affect the health of human beings. The experts of solar energy started rapidly and effectively treat most of the negative chemical impact that solar panels have. So, it is important to have high quality solar panels in our project with different sizes. The project team started testing these panels' quality and make sure of the panels' effective work.

2. Results

Design Progress of (FSRC)

In the beginning, it was important to note that all work was done on campus for the very first time at Prince Mohammad Bin Fahd University. Several tests and adjustments were carried out in designating and manufacturing the car components to different group working in parallel in a very short time period.

Balancing the different sheets from different areas was difficult especially when fixing mechanical and electrical parts. Furthermore, it was important to distribute team members according to their specialties to save both time and effort while designing the flat sheets.

All mechanical structures were well tested to support the safety mood especially with the wheels and supporting sheets with the metal bullets in the different sizes. A fiberglass mold is rather simple to make, but it takes a few days. The idea of a mold is to make a replica of the item that you need. You will be able to reuse the mold many times after. Figure 1 shows the wooden mold that was prepared for the structure of the car. Nowadays, university teams are using CNC machines to produce male models of their solar vehicle. They produce female molds by using these male models and they manufacture exterior of the vehicle by using these female molds. The computer model was transformed into a full scale

model which was then used to produce glass fiber and resin molds capable of withstanding high temperatures. These molds were then used to construct a composite Kevlar/Nomex honeycomb/Kevlar body using a high temperature vacuum bagging technique, in an autoclave at a temperature of 175°C [18].

miscellaneous, normal pliers, brushes, punches and special chisels, extractors, wrench sets, files, hammers. Imported air jacks, axle stands, and bottle jacks, crane accessories were used to move the solar car while fixing some parts inside the array and in different parts of the body (Figure 2). In addition, engine stands borrowed from workshops were used to fix the



Figure 1. Wooden mold of the design (made in PMU)



Figure 2. Images of students doing their hand tools work.

2.1. Hand Tools

tools accurately together with folding cranes and Jack accessories.

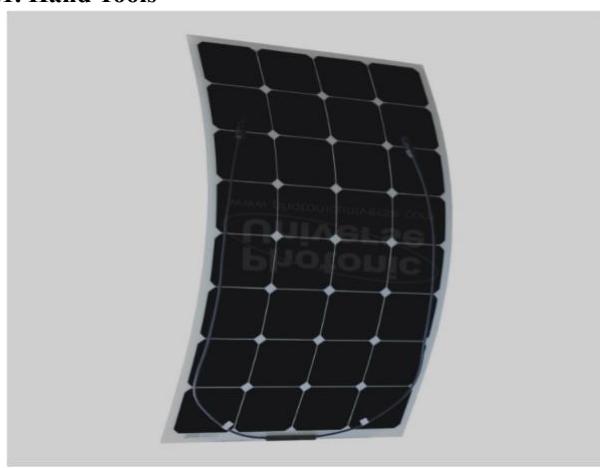


Figure 3. Flexible solar Panel

2.2. Solar Panel

Efficiency Advantages:

- 1) Most energy from less space: SunPower X-Series solar panels deliver 44% more power per panel.² which means you can create more power in smaller spaces, with fewer panels. And, you can position them on the sunniest parts of your roof [12].
- 2) Most electricity: Simply put, SunPower X-Series panels produce more electricity than conventional panels. They convert more sunlight to electricity, producing 75% more energy per square foot over the first 25 years. [3, 4, 14]
- 3) Most flexibility: Because X-Series residential solar panels generate more electricity from a smaller area,

In addition there were important hand tools which help members to fix in the different parts such as locking pliers,

you can expand energy production simply by using additional roof space to add more panels later [15].

- 4) Most peace of mind: More guaranteed power. SunPower offers the best combined power and product warranty over 25 years [5]. And because they're built on a solid copper foundation, SunPower solar cells deliver unmatched reliability over the lifetime of your solar energy system [6, 7].
 - 5) Most beautiful: X-Series panels are offered in SunPower® Signature™ Black, designed to blend harmoniously into your roof. Built using all-black solar cells and anti-reflective glass to reduce glare, the premium aesthetics can accommodate a variety of architectural styles [15].

Solar panels are 100 watts each shown in figure 3 (mono-crystalline type) capable of producing a total of 1000 watts with up to twenty two percent efficiency. The panels were attached to the top surface of the cars for the benefit of harnessing most of the solar energy.

It's a fact: Residential solar panels from SunPower produce the most energy of all solar panels on the market. Because SunPower home solar panels are so efficient, you can make the most of your roof space to produce significantly more electricity. What does this mean for you? Highly efficient

solar panels from SunPower generate more energy over the lifetime of your system than other panels which means that over the lifetime of your system. 100W high efficiency flexible solar PV panels, high efficiency, back contact, SunPower cell sun power specifications [5]. The back contact solar panels for off-grid and on-grid systems has 19% - 23% high efficiency. The high efficiency solar PV module adopts the world's highest efficiency cell with efficiency up to 23%, and the efficiency of the module is 25-30% higher than the traditional once this cells positive pole and the negative pole are on the same side maximum sunlight, so that it can get the maximum power [5, 6].

2.3. Body and Chassis Design

The figures shown in 4, 5 and 6 were done originally using the Sketch up drafting software. Aerodynamics calculation was done and the body was designed accordingly. In figure 7, the final assembly and testing of the car was carried out around campus road. The car was ready and qualified to participate in the worls solar challenge at Abu Dhabi, Fall 2014. But due to logistical problems the team could not deliver and the decision was made to participate in the next event.

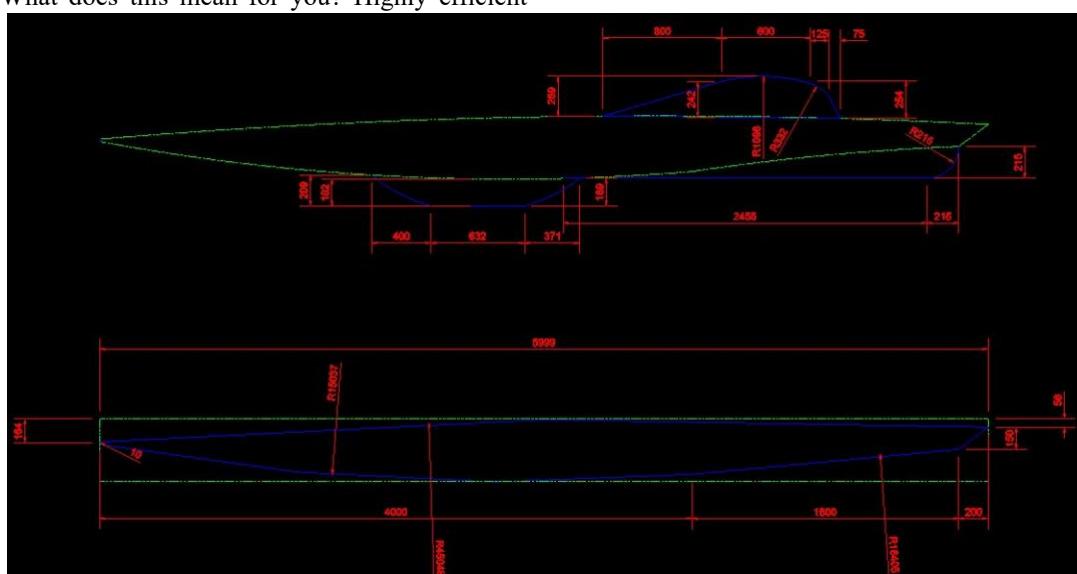


Figure 4. AutoCAD (BODY):

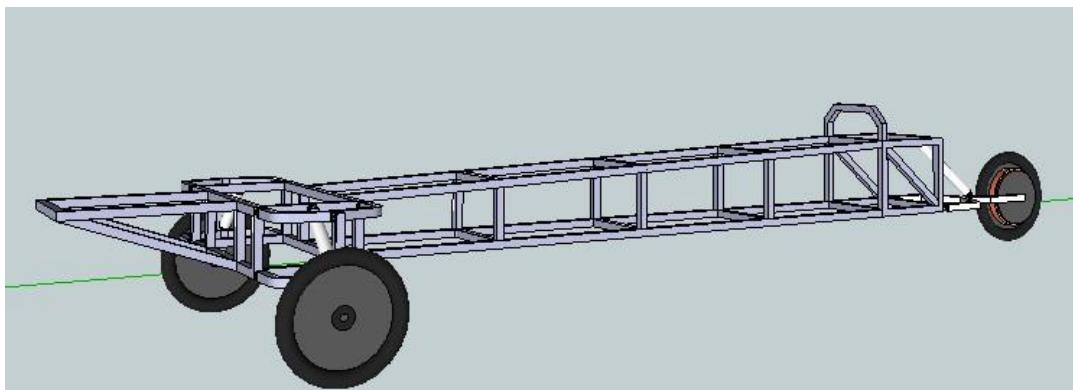


Figure 5. Sketch up Program (CHASSIS): Chassis.

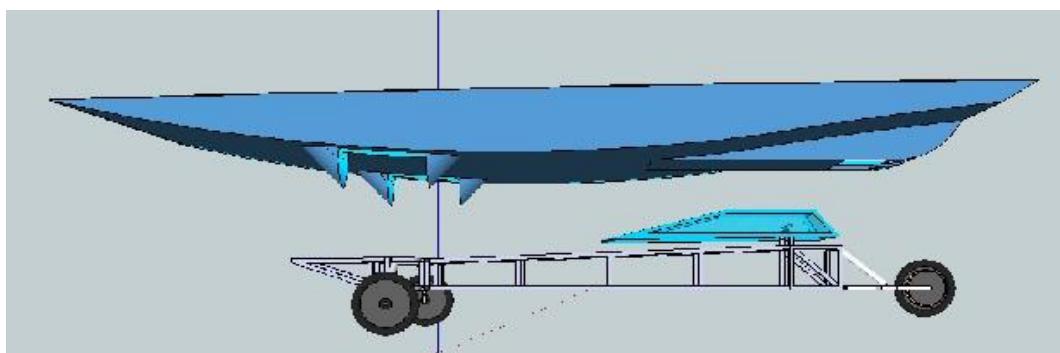


Figure 6. Full body design- exploded



Figure 7. Finished car as build and tested at PMU

2.4. Specifications

Table 1. Table of car Specifications.

Length	6 m
Width	2 m
Height	1.2 m
Car net Weight	300 kg (Include passenger)
Seating Capacity	One Passenger
Chassis	Aluminum Tube(40X40mm)
Tire	Taiwan, Diameter= 40 cm X 8.5 cm thick
Wheel Base	410 cm

Suspension	Front : Double wishbone, Rear : Trailing arm
Maximum Speed	120 km/h (estimated)
Solar Array	100W high efficiency flexible solar PV panels Produced by: SUNPOWER Co. size (1050*540*3mm) Cell efficiency 19.9%
Steering wheel	Linkage
Torque	Power=time*rpm T=26 N.M
Motor	Brush AC Direct Drive Motor with 3 Phase Controller (2.200 KW), 1700 rpm
Battery	LEAD-ACID Battery
Brake	Hydraulic Disc and Regeneration Brake

2.5. Air Drags Force Analysis

In solar car races where efficiency determines the winner, the mechanical aspects of the car are responsible for minimizing many forms of energy losses. Aerodynamics is a large contributing factor [16], as drag increases exponentially with the speed of the solar car. Another significant factor is rolling resistance, which is encountered from the types of tires used and the geometry and movement of the suspension systems [17].

Table 2. Drag and lift coefficients summary

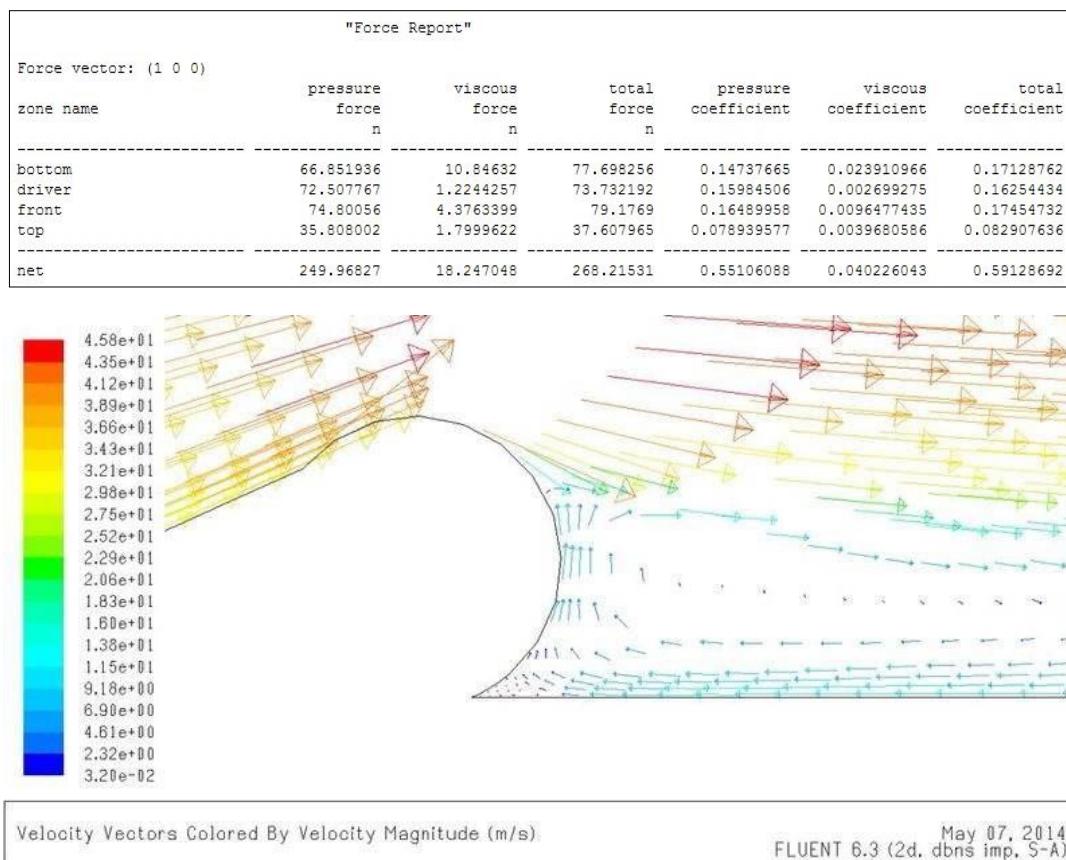


Figure 8. Velocity vector of the air.

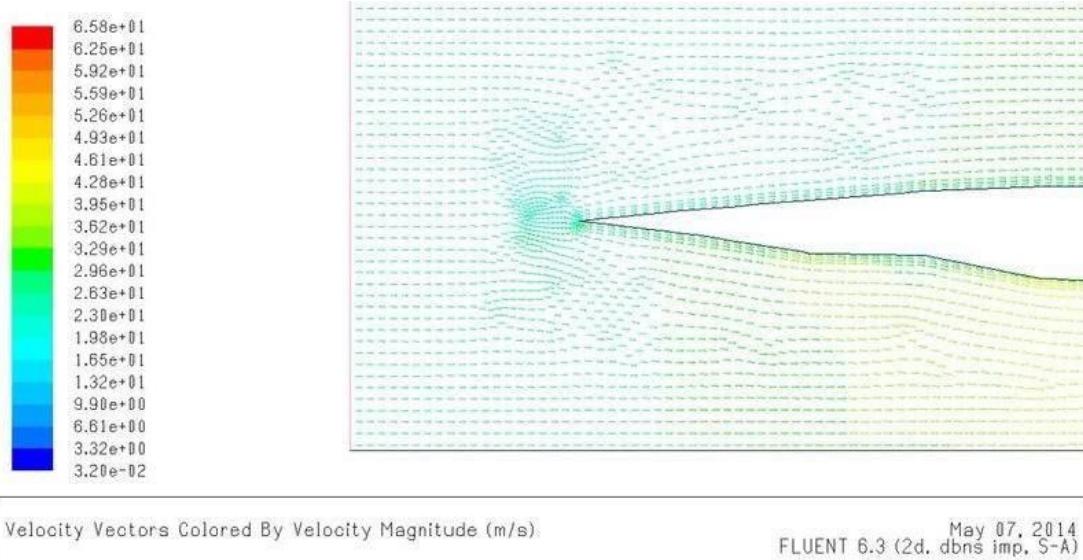


Figure 9. Velocity vector of the top

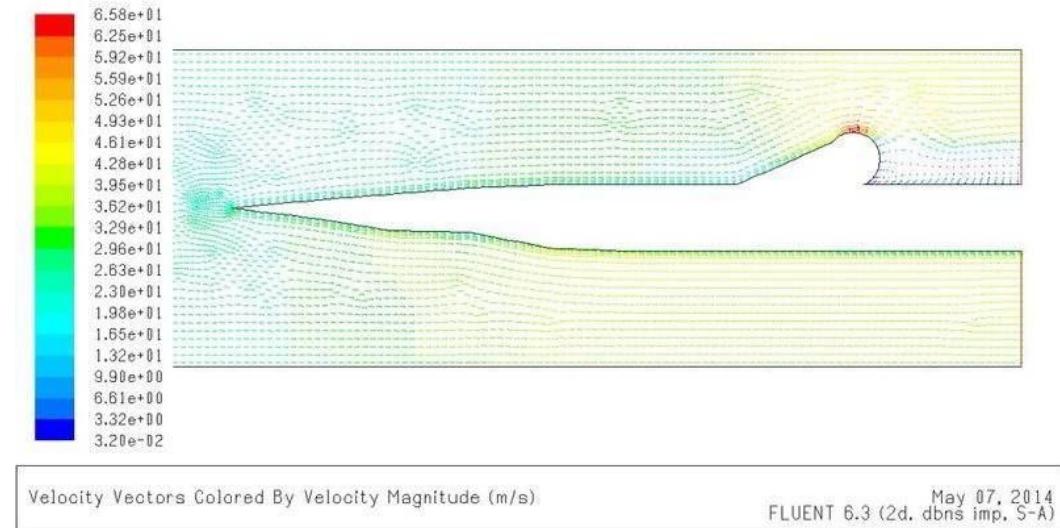


Figure 10. Velocity vector in front side of car

For the aerodynamics simulation, a fluent program was used (Fig. 8, 9 and 10). The finite volume method was implemented with a boundary layer mesh and no slip conditions. Table 2 shows all the calculated results for the pressure and viscous forces using the following equations:

$$\frac{LL}{DD} = \frac{11/22\rho p p p V V 22}{11/22\rho p p p p V V 22} , \quad C_D = \frac{11}{22\rho p p p p V V 22} \quad (1)$$

Where C_L : pressure coefficient

C_D : viscous coefficient

L: lift forces

D: drag forces

P: density of the air

A: projected frontal area

V: speed of the car

For frictional force calculation

$$F_r = C_{rr}W \quad (2)$$

C_{rr} : coefficient of rolling

W: total weight of the car

The required power to overcome all resistance forces

$$P = F V \quad (3)$$

F: total resistance force equal to $F_d + F_r$

Combining Equations 1,2 and 3 where $C_D=0.04$ (Table 2) and $C_{rr}=0.004$

$$P = \{C_D A p V^2 / 2 + C_{rr} W\} V \quad (4)$$

Reduces to

$$P = 0.128V^3 + 12V \quad (5)$$

Therefore, if velocity is assumed at 80 Km/hr then from equation 5 the required power to overcome the total resistance is $P = 407.21$ watts (table 3)

Table 3. Velocity of the car and the require power to overcome resistance

Speed (km/h)	Speed (m/s)	Required Power (w)
0	0	0
10	2.777	33.17
20	5.555	69.49
30	8.333	122.05
40	11.11	163.97
50	13.88	228.20
60	16.666	308.47
70	19.444	407.21
80	22.22	527.89
90	25	673.68

Table 3 shows sample calculation of the car velocity and the power required. The maximum solar power that can be attained by the solar panels is

$$P_{\max} = P \eta \quad (6)$$

Where P : is the solar flux available and measured at the city of Dhahran (Figure 11)

η : efficiency of the solar panels (mono crystalline type rated at 20 %)

$$P_{\text{solar}} = A P_{\max} \quad (7)$$

Where A : total area of solar panels And
 $P_{\text{solar}} = 11(0.54)(200W/m^2) = 1188$ Watts

Assuming power losses 18% then the total power loss is 213.84 W. The total power available is 974.16 W

2.6. Electrical Design

AC Direct Drive Motors were manufactured and assembled with 3 Phase Controller of providing 2200 watts and 1700 rpm. Batteries of LEAD-ACID types were used in the test of storage capacity 4800 watts. The primary design of these motors is to generate more power and thus increase the speed of the car. For example for the initial speed one motor will start and as speed increases gradually more motors will run. Phase two of the study will involve the following:

- a) Testing and verification of enhanced electrical system performance efficiency, including the solar energy generation, energy storage (lithium batteries), energy conversion to AC, motor wire efficiency, and the overall electrical to shaft efficiency.
- b) Mathematical modeling and physical testing of the gear box ratios, material selection, fabrication methods, and system integration.
- c) Mathematical modeling and physical testing of the car weight distribution and dynamics at various speeds, up to the desired objective.
- d) Assessment of the car suspension system and system enhancements

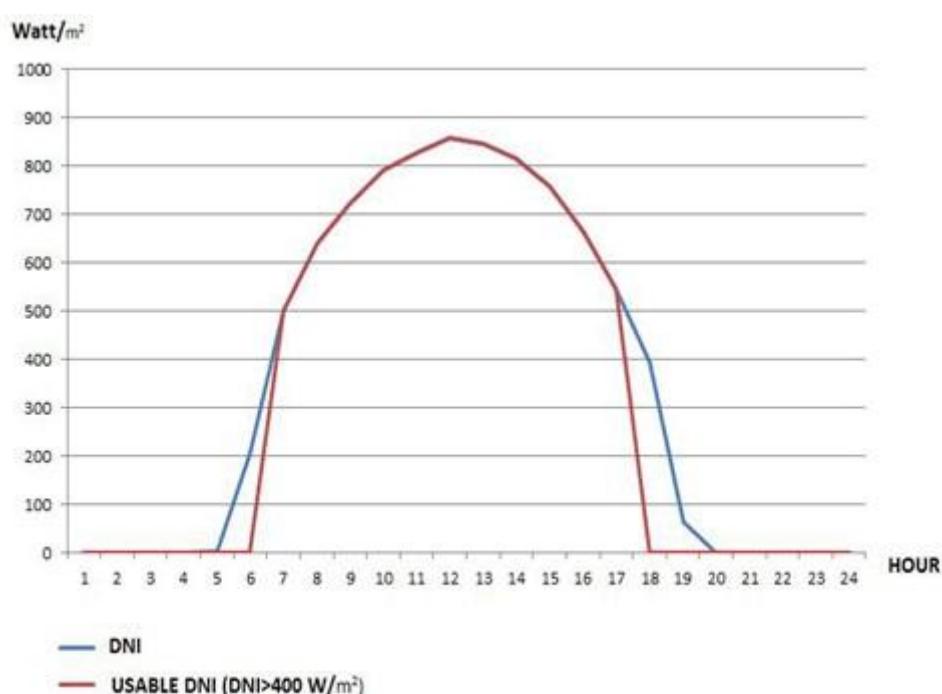


Figure 11. Solar intensity for the city of Dhahran, Saudi Arabia

A total of eleven solar panels were used at $P_{\max} = (800)(20\%) = 200$ W/m²

The total solar power output

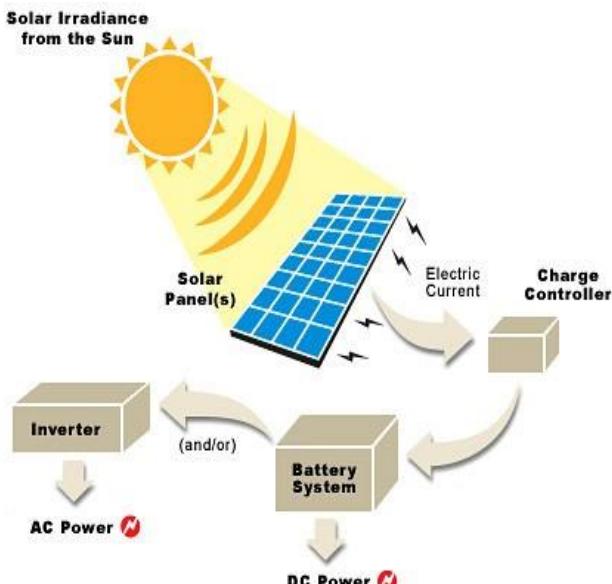


Figure 12. A typical solar System diagram

A typical solar system diagram (Figure 12) showing the connection from the solar panels to MPPT and then to batteries and finally connected to DC motor. A four batteries were used with capacity of each battery is 100 AH, voltage, 12 volt, and Wight of battery , 29 Kg. The inverter is 12 V DC-220 V AAC with 3000 watts. The storage capacity of the batteries is

$P_{elect} = V I = 4800$ watts. The time taken for the car to be running on the batteries is four hours. Motor is producing 1725 rpm at 2350 watts where the max speed is 91.26 Rad/sec and the velocity is 70 Km/hr.

3. Conclusions

There are many reasons for designing the new solar car in Saudi Arabia and all Gulf States. Solar energy is available and cheap in the natural resources where technology plays important and significant roles to use the tools of solar energy. It is also important to add more advantages to the industrial support from Saudi factories that use solar energy in different methods of safety mood. This current design of solar car will reduce the use of fuel energy and guide more factories to rethink in using solar energy not only in auto motors, but also in other mechanical uses. Solar cars will be in need to support solar panels and the different instruments for mechanical and technical design. The project is considered a challenge point that will use the advantages of awareness which will have sustainable industrial methods in the field of alternative energy.

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