HELIOS; A SOLAR VEHICLE DESIGNED THROUGH AN ANTHROPOCENTRIC AND REALISTIC VIEW

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Abstract

One of the major issues of our times is the exhaustion of the non renewable energy resources, like petrol. In addition to that, the effort to reduce the CO2 emissions and to confront the ozone problem, led the scientific community to the exploitation of the renewable energy resources, like the solar energy. The design of solar vehicles, mostly by academic teams, is part of this task. The majority of the solar vehicles have a sophisticated form, based on racing factors and standards. This prevents them from giving realistic solutions over the design of a solar vehicle for everyday use. The current project proposes a rational design of a solar vehicle, aiming to a feasible solution that can reach the production line. It emphasizes on the structure quality and the reduction of the construction and assembly costs. Moreover, key part plays the ergonomics and the driver's comfort. Also, it takes under consideration the difficulties of the every day city use, achieving finally a practical, but most of all viable design.

Key words: Solar vehicle; anthropocentric design; viable; structure quality.

Resumen

Uno de los principales asuntos de esta época es el agotamiento de los recursos energéticos no renovables, como el petróleo. Además, el esfuerzo de disminuir las emisiones del CO2 y enfrentar el problema del ozono, ha conducido a la comunidad científica a la explotación de los recursos energéticos renovables, como la energía solar. El diseño de vehículos solares, sobre todo por los equipos académicos, es parte de esta tarea. La mayoría de los vehículos solares tiene una forma sofisticada, basada en factores y estándares de carrera. Esto evita que den soluciones realistas sobre el diseño de un vehículo solar para un uso diario. El proyecto actual propone un diseño racional de un vehículo solar, apuntando a una solución viable que pueda llegar a las líneas de la producción. Pone énfasis en la calidad de la estructura y la reducción de los costes de la construcción y del montaje. Además, en su diseño juega un papel importante la ergonomía y la comodidad del conductor. También, tiene en consideración las dificultades del uso diario en la ciudad, alcanzando finalmente un diseño práctico, pero sobre todo viable.

Palabras clave: Vehiculo solar; diseño antropocéntrico; viable; calidad de estructura.

1. Introduction

The exhaustion of the non renewable energy resources, like petrol, in addition to the effort to reduce the CO2 emissions and to confront the ozone problem, led the scientific community to the exploitation of the renewable energy resources, like the solar energy. This made designing and constructing solar vehicles a popular scientific activity among research groups, technical institutes and universities. Despite the simple functional principles that solar vehicles are based on, they include the state of the art of the specific technology field, which moreover is vastly developing, due to competition. Solar vehicles are no more simple applications of the current technology, but platforms for developing new technologies and production methods for the storage a nd use of solar energy. Indicative, vehicles that are used as means of projection of technological innovations can exceed in cost the certain millions of euros.

The history of solar fighting vehicles begins in 1983 when the Australians Hans Tholstrup and Larry Perkins managed to cover the distance from Sidney to Perth, a distance above 4000 km, in 21 days with their vehicle BP Quiet Achiever, achieving a medium speed 23 km/h. This achievement prompted also other teams to attempt similar efforts, reaching today to the Dutch Nuna II of the universities of Delft and Rotterdam that managed to cross 3000 km in almost 31 hours, with medium speed 97 km/h.

Developing and manufacturing a solar vehicle serve multiple objectives so much in scientific as in educational level. The common objectives are:

1. The education of new engineers through organizing, designing, and manufacturing the vehicle.
2. The constant development of the technologies of exploitation of solar energy.
3. The improvement of the sub systems for handing and transforming the solar energy.
4. The promotion of the capacities of renewable sources of energy and the sensitization of the wider public on environmental protection issues.

Nevertheless, the relatively low performance coefficient of the photovoltaic panels, and the particulate nature of these vehicles that aim to the minimization of the energy consumption, constrict the engineers and impel them to create vehicles of strange form. Until now, they are unhandy and far from something that can be used for everyday transportation. Moreover, the sophisticated mechanical and electrical parts increase the fabrication cost to astronomical, for a vehicle, levels. Looking towards the future, a change in the confrontation of the design of solar vehicles is needed, in order to transform them into a realistic solution for an ecological transportation.

Thus, the current project included two additional factors:

1. The anthropocentric design
2. The viability of the design.

The outcome of the project is a drivable vehicle with a reasonable fabrication cost. The innovation of the project lies in the different approach of solar vehicles, which influences the conceptual design process, the final form of the vehicle and the blending of the customized with the commercial mechanical parts.

It must be noted, that the current project took part and won a Pan-Hellenic competition held by the ministry of civilization, which took place in the scope of the Olympic games of Athens. [1]

2. Solar Vehicle Technology

Racing solar vehicles incorporate the state of the art of technologies that is not visible on the first look. Restrictions of dimensions, energy deposit and total weight, as well as the high competition, impose the use of materials and parts of high cost. The engineering knowledge that lies behind the design and fabrication of a solar vehicle is tremendous and extend further from purpose of the current article; therefore in the following chapter only a brief review of the solar vehicle technologies will be made.

The function principle of solar vehicles is simple; the solar energy strikes the solar generator that is found in on surface of vehicle and transforms into electric energy (Fig.1). Afterwards the electric power is changed with converter DC/DC in the required voltage, in order to charge the storage cells (batteries). The stored energy is led to the engine through a controller that determines the rotation and the torque of engine. Finally the power train transmits the power of engine to the wheel. There is also the possibility of energy recovery through braking, by inverting the force flow and using the engine as generator. Certainly, the above scheme is a generalization and can vary depending on the engineers' point of view.

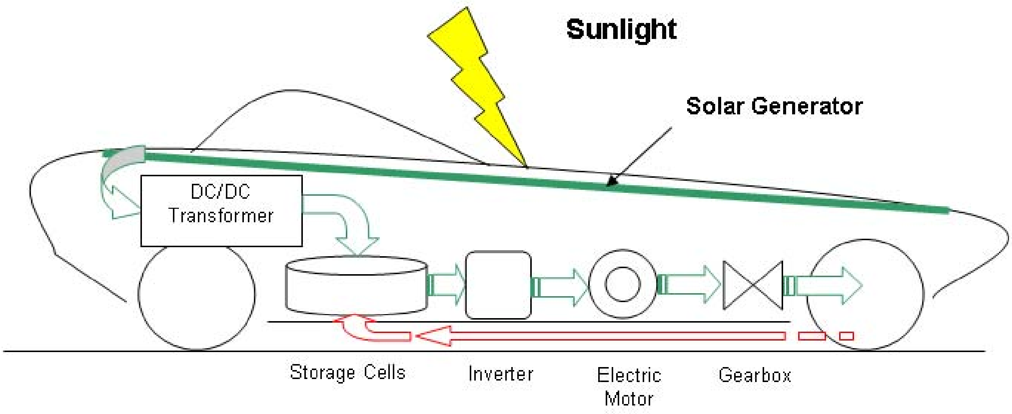

Figure1. Solar vehicle function principle

2.1 Solar Generator

The solar generator is made by hundreds independent photovoltaic elements which are appropriate connected with each other, for the production of electric energy. The most common material used for fabricating photovoltaic elements is the silicon, which is a semi-conducting material. The performance coefficient of the photovoltaic elements is found in the region the 15- 30%, while their cost increases exponential in relevance with the increase of their performance. Considering that in the Mediterranean countries the nominal value of solar power is equal to 1000 W/m ^{2} (noon of summer day), a solar generator of 10 m ^{2} can attribute 1500/3000 W .[2][3]

2.2 DC/DC transformer

Solar radiation does not have a constant intensity during the day; therefore the power produced at the solar generator continuously alters. Moreover, the output of the batteries also alters, depending on their charge. Therefore, in order to improve the performance of the solar generator, a voltage transformer is imposed, which has the ability of regulating the voltage output of the photovoltaic elements. These appliances are called Maximum Power Point Trackers (MPPT) and improve radically the performance of the system.[4]

2.3 Storage cells

Solar energy is sufficient enough to move the vehicle, by directly connecting the generator with the motor. Nevertheless, the use of storage cells (batteries) has a significant advantage. It allows the storage of energy when the vehicle is not led or by retrieving energy through braking. The important characteristics of the storage cells are their storage capacity and their discharging rhythm.

The low cost solar vehicles use normally lead-acid storage cells, similar to passenger vehicles. The more expensive ones use storage cells of lithium-ion with liquid electrolyte, which are up to four times lighter but also many times more expensive.

2.4 Electric motor

The majority of solar vehicles use synchronous, wound rotor, AC electric motors, of more or less 8hp. In order to regulate the direct current of the batteries and transform it into alternate current for the motor, an inverter is imposed, which is controlled by the driver, through the accelerator pedal. Again, the motors used in solar vehicles are not cheap commercial models, but expensive ones that have performance coefficients within the range of 95-98%.

The power train can be achieved either through a gear box, or as it is usually done, connecting directly the motor to the wheel. The advantage of the direct connection is that it does not present the usual power losses.[5]

2.5 Aerodynamic performance

Aerodynamics plays a great role in the design of solar vehicles. In high velocities, for example 100km/h, almost the 70% of the motors power is used to overcome air resistance. This marks out the need of reducing to the minimum the drag coefficient and the vehicle’s cross-section. This is achieved with the use of aerodynamic forms for the vehicle (drop type), smooth and frictionless external surfaces, small ventilation intakes, etc. The drag coefficients of the modern solar vehicles are within the range of 0.1, contributing vastly to energy conserving.

2.6 Chassis and external surfaces

It is common place, in solar vehicles, the use of monocoque chassis made from composite materials, containing carbon fibbers, Kevlar or Nomex, while some external surfaces can also be made by polyester. However, the relative low weight of the vehicle, results to small mechanical loads that can also be supported by a light steel tube chassis, lowering the significantly the cost.[6]

2.7 The AUTH approach

The design of a solar vehicle comprises a difficult and time consumption process. There are many issues that need to be confronted that are sometimes controversy. Thus, the engineering teams tend to adapt extreme designs and solutions that ignore the human factor and focus on mechanical issues. Moreover, the solar vehicles are usually made for specific uses, like races or exhibitions, and are far from proposing a realistic design. Classic examples are the Dutch Nuna and the Australian Aurora, which though they have excellent technical characteristics, they are over sophisticated and not easy driveable vehicles.

The current project approaches the design of solar vehicles from a different angle. Although it creates a vehicle designated for races, the ergonomics and viability play key role. The main objectives were to create a vehicle that will respect the driver, providing a decent and ergonomic driving position, that can handle the difficulties of national motorways and that will have a reasonable fabrication cost.

3. Results

3.1. Methodology

In order for a solar vehicle to be competitive, a tremendous effort to reduce the energy losses is made. This effort imposes the use of extreme design solutions and state of the art technologies that puss the fabrication cost to the limits. Main objectives of our team were to create a driveable vehicle, fabricated within a reasonable cost.

Instead of searching for optimum mechanical solution for every component and in extension for the form of the vehicle, we chose to adapt the design to the driver. That means that the vehicle was designed from the inside towards the outside. The analysis that followed each design issue was firstly aimed at providing comfort to the driver and afterwards high performance to the vehicle. Thereupon, the proposed design solutions were ranked based on their cost and their manufacturability and the optimum one was chosen, taken under consideration previous experience of real life tested designs. Due to the numerous parts that a solar vehicle is compiled from and compatibility issues of each part with its surroundings, small design loops were inevitable. Moreover, some times the logic of fabricating more than one different design for one part was adapted. Later, the assembly of the particulate parts was evaluated and the optimum was chosen; this way valuable time was saved. Also, each part of the vehicle influences the performance and needs to be in compatibility with the whole system. None of the parts, mechanical or structural, can not be calculated, designed or chosen if these factors are not first checked. Therefore, the design process was conducted through meetings where all teams that form part of the project where present and participated in. This way, a functional and harmonic design is accomplished faster and moreover the cost is reduced by avoiding extensive re-design and re-fabrication of vehicle parts.

Entering the conceptual design process, it was considered as fundamental that the driver must have a comfortable, normal passenger's car, driving position. Therefore, the classical horizontal wing vehicle form had to be rejected. The aim was achieved by selecting a totally different, from the commonly used, vehicle form that incorporates two vertical wings instead of one horizontal; a passenger's car seat can then be used. Launching from there, the frame of the vehicle was designed, providing a robust cage to protect the driver, place for the control elements of the cockpit and support of the suspension, the steering and all the other apportion elements. As it concerns the mechanical parts of the vehicle, in order to assure endurance and maintain low cost, a combination of customized with commercial rather than exotic parts, was made. An analytic description of the vehicle follows.

3.1.1. Design of the vehicle

The prototype vehicle comes with the name "HELIOS" and its form can be seen at Figures 2-3. It comprises of two vertical wings, one small and one bigger, and a planar solar generator. The drive wheel, the front wheel and the driver's seat can be found in the bigger wing; while the smaller one hosts the storage cells.

The selection of vertical wings has the following advantages:

- For the same volume requirements, leads to smaller cross-sections
- They have excellent driving stability
- Provides the possibility of having a typical wheel suspension, taken directly from small motorcycles
- The driver seat has the normal, passenger car, form
- The driver can easily access the seat from the side way, with no extra help

So that to further reduce the air resistance the NACA 0012-64 wing with a curve configuration of the lower surface was selected. For the measurement of drag coefficient a prototype in scale 1:10 was produced, which was measured in the wind tunnel of the *Laboratory of Fluid Mechanics and Turbomachinery of the Aristotelian University of Thessaloniki*.

The model has drag coefficient equal to cd = 0.22. Consequently, the air resistance of the vehicle, which has a cross-section of A = 0.71 m^2, is equal to A×cd = 0.16 m^2, which constitutes one from the smaller for solar vehicles of this category.

For the manufacture of the chassis, stainless steel rectangular beams were selected. The particulate beams have a cross-section of 25 × 25 mm^2 and 50 × 50 mm^2 and thickness of 0.8 mm, and made from stainless steel 1.4401 (316 X 5 CrNiMo 18 10) with fracture limit 550 [N]/mm^2, yield limit 210 [N]/mm^2 and allowed breadth for alternating load 160 [N]/mm^2.

The static analysis of the frame was performed using a mesh of 88 nodes and 140 beams. The maximum total tension at the ends and middle of each beam was calculated using the Finite Element Method.

The beams were simulated by means of BEAM 4 (ANSYS 5.7) elements using 6 Degrees Of Freedom (DOF) per node. The nodes were defined as solid, thus also incorporating torques. It was also considered that the frame was supported at the suspension connecting points. The stresses produced by the combined mass of the frame, the driver and all the parts that are connected to the frame, when the vehicle decelerates by 1g where applied on those nodes. The assumption that those stresses are alternate was made, so as to take into account the fact that they change with time.

The maximum stresses were found to be 116N/mm^2. Taking into account that the maximum permissible stress is 160N/mm^2, it was derived that the safety factor for the worst case scenario was 1.36. Thus the frame is functioning within its strength limits, and hence has a, theoretically, infinite life span.

For the suspension and the brakes, commercial parts were used, taken from a small motorcycle (250 cm^3). Through that, the fabrication cost decreases significantly, while the essential reliability is ensured, because the elements used have been calculated and tested for heavier loads and reached the manufacture line.

Finally, for the steering, a pair of snail-nut was used to connect the steering wheel with the front wishbone, providing the necessary stability, reliability and almost zero tolerances.[7-11]

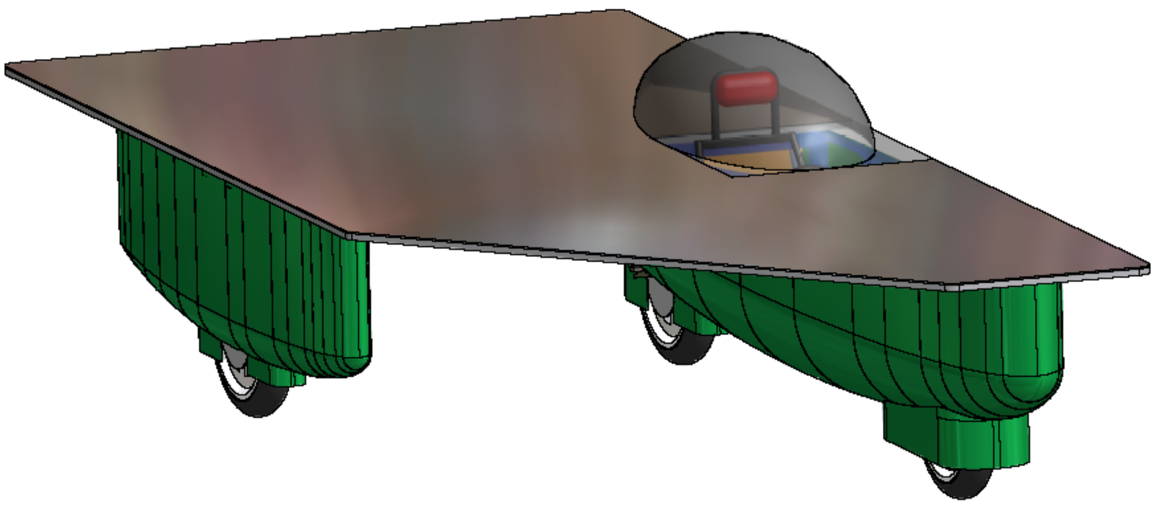

Figure 2. Isometric view of Helios

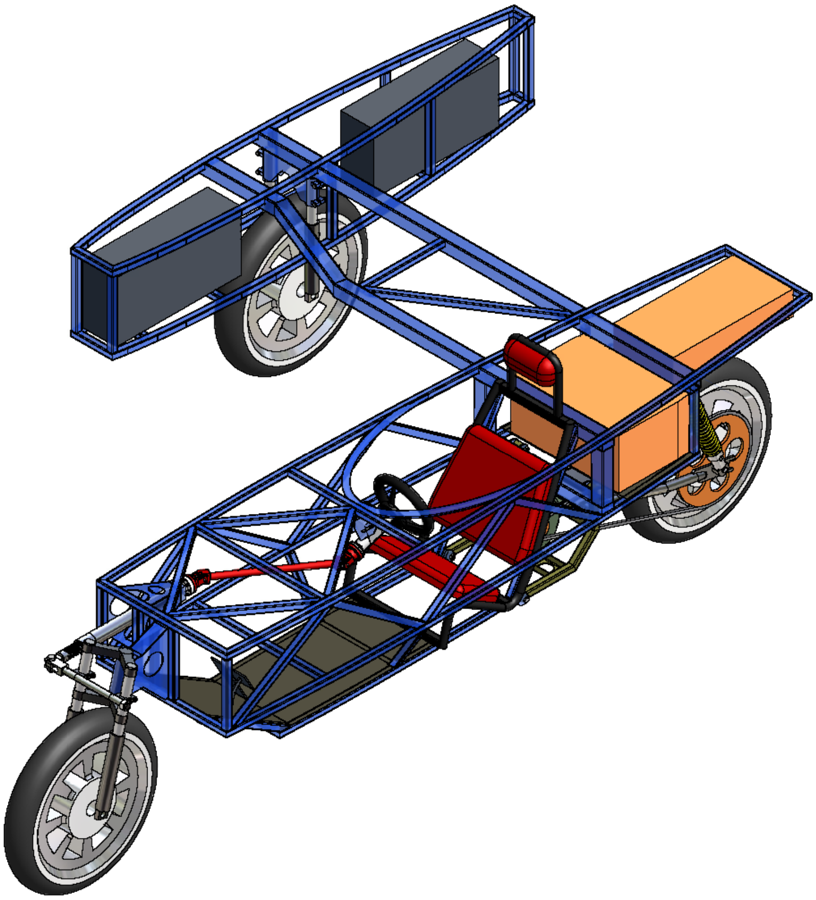

Figure 3. Isometric view of Helios chassis

3.2 Subsystems' selection

3.2.1 Photovoltaic elements

After the relative research on the photovoltaic elements and considering the cost-performance ratio, a microcrystalline silicon element was selected, with a performance coefficient of 20%, made from the company SunPower (A-300). The choice of elements of double or triple junction was rejected, due to the multiple higher costs (10 to 200 times), while their performance is only 50% better.

3.2.2 Storage cells

In the storage cells field, there are two prevailing technologies concerning the Lithium-ion batteries. In the first type, the electrolyte has a liquid form and is under pressure and in the second type is polymeric gel. The second solution has better performance and is safer, while the first has smaller cost. Once again, with criterion the ratio cost/output, but also the available weight, the Lithium-ion with liquid electrolyte type is selected.

3.2.3 Electric motor

The majority of solar vehicles use a DC-brushless electric motor, which is light, has great technical characteristics, a high performance coefficient and can also be directly connected to the drive wheel. However, this solution is quite expensive and does not give the possibility to the engineers to interfere in its characteristics.

Nevertheless, similar performance can be achieved by a common synchronous, wound rotor, AC motor combined with an inverter. The particulate solution has the advantages that it doubles functional range of the motor, it provides excellent torque characteristics, it allows the achievement of speeds over the 120 km/h for the specific application and most of all it reduces considerably the cost. Also it allows energy recovery during braking, while the performance coefficient in the critical region remains better than 85%. At the same time, it has great control, which allows also the use of different mapping for the motor depending on the conditions of the street or the day's sunlight. Its main disadvantages are the bigger weight and the need of a transmission system for the power train.

According to the above, a Siemens bipolar, three phase, 50 Hz AC, motor was selected, with a nominal power of 4 kW. Moreover, through the inverter, the motor can be over boost up to 6 kW.

3.2.4 Transmission system

Due to the selection of the specific electric motor a transmission system for the powertrain was designed. The power train is achieved through a low friction chain and a two speed gearbox. The main disadvantages a gearbox are the power loses and the additional weight. On the other hand, it facilitates the start of the vehicle and the course on ascent roads, which finally leads to saving energy; while the driver can also use it to break the vehicle and charge the batteries. The gearbox used, was totally designed and manufactured in the *Laboratory of Machine Elements and Machine Design of the Aristotle University of the Thessaloniki*. It comprises of two pairs of helical gears, a clasp clutch and a shifting mechanism, while in order to reduce friction losses we used labyrinth sealing for the bearings instead of gaskets.

4. Technical Characteristics

According to the analysis presented in the previous chapter, the following table of technical characteristics arises, which complies with the FIA, cat.1-class 2, regulations for race solar vehicles:

Helios technical characteristics		
1	Height	1.130 m
2	Length	4.910 m
3	Width	1.800 m
4	Track width	1.350 m
5	Wheelbase	2.437 m
6	Weight	220 Kg
7	Wheels	3: Front, Drive, Sidelong
8	External Surfaces	Carbon

9	Photovoltaic Elements	6.9 m^2, perf. Coef. = min 20%
10	Storage cells	Li-ion 29.4 Kg 100.8 V
11	Seat	1
12	Chassis	Stainless steel beams
13	Brakes	Front, Sidelong: Hydraulic
		Rear: Hydraulic
14	Handbrake	Yes (rear wheel)
15	Suspension	Front, Sidelong: Hydraulic telescopic forks
16		Rear: Swingarm
17	Steering	Mechanical; Snail-nut pair
18	Solar generator	1.34 kW
19	Motor	Siemens, synchronous AC wound rotor,6 kW (up to 10 kW, with inverter)
20	Drag coefficient	0.22
21	Cross-section	0.71 m^2
22	Aerodynamic coefficient	0.22×0.71 = 0.156 m^2
23	Max. Speed (flat terrene)	124 km/h
24	Max speed (18% grade)	32 km/h

Table1. Helios technical characteristics

5. Vehicle performance

In order to carry out performance tests for the vehicle, the relative computer code was developed. The power needs were calculated based on the air resistance, the wheel resistance, the accelerating forces and the terrene grade; then considering the performance coefficient of every sub system, the energy consumption was calculated. Moreover, the solar generator's output was calculated based on two different sunlight scenarios. The tests were curried out in the *Laboratory of Applied Thermodynamics of the Aristotle University of Thessaloniki* and the results can be seen at Figure4.

According to the tests, the vehicle can accelerate from 0-100km/h in 36sec and can reach a speed of 124km/h.

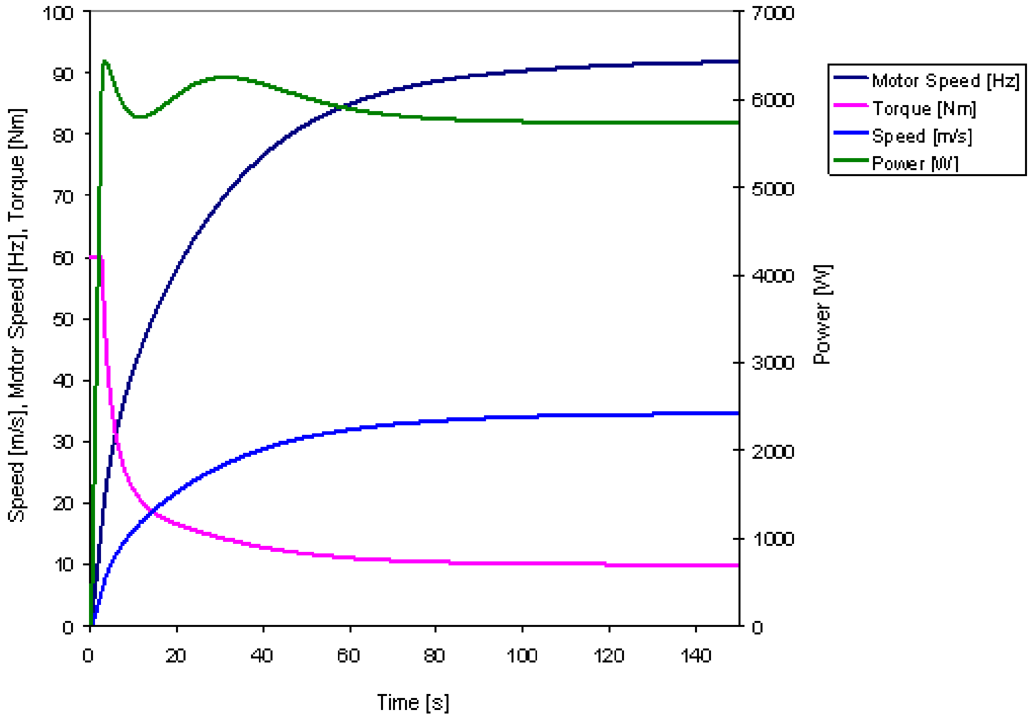

Figure 4. Helios performance

6. Conclusions and Discussion

Taking advantage of the Olympic Games of Athens, the relative committee organized an international solar vehicle race in Greece, to promote the need of global environmental thinking. In parallel, a competition was held to appoint the vehicle that would represent Greece. That contest was won by the dept. of Mechanical Engineering of the Aristotle University of Thessaloniki and the designed vehicle is presented in the current work. Moreover, this initiative set the corner stone for more projects concerning solar energy in Greece, which is a scientific area that has great interest for the mediterranean countries.

The majority of the solar vehicles, designed by academic teams, have a sophisticated form, based only on racing factors and standards. Furthermore, the use of refined mechanical and electrical parts increase the fabrication cost to astronomical, for a vehicle, levels. All these prevent them from giving realistic solutions over the design of a solar vehicle for everyday use.

We approached the theme from a different angle and set as objectives an anthropocentric and viable design. We chose to adapt the design of the vehicle to the driver, providing a comfortable, normal passenger's car, driving position and easy access to the cockpit. In order to achieve this, a totally different vehicle form was chosen. The use of two (2) vertical wings was preferred against one horizontal that most solar vehicles use in order to improve the aerodynamic performance. This provided the potential of creating a similar to a passenger's car cockpit. Furthermore, it gave the possibility to equip the vehicle with a typical motorcycle suspension that provides comfort and eliminates crackling issues, due to the terrene's roughness. All the mechanical parts are either prefabricated or made by commercial alloys, maintaining the cost in low levels and providing the necessary reliability.

Finally, all the fabrication processes are plain, using tools that can be accessed in any machine shop.

The current project managed to design and fabricate a driveable and also competitive solar vehicle. Moreover, we managed to maintain the cost at low levels, that is less than two hundred thousand euros; while solar vehicles of the particulate category, and mostly the ones that are used to promote specific technologies, can reach up to a cost of one million euros, even higher some times.

The importance and marksmanship of the project and our methodology is also established by the fact that lately more and more academic teams tend to follow a similar trend for the design of solar vehicle, rejecting the early forms and adapting the use of vertical wings that can host the driver's seat.

Looking towards the future, a change in the confrontation of the solar vehicles is needed, in order to transform them into a realistic solution for an ecological transportation. A successful first step was made and that gives hopeful perspectives for the future. It is our opinion, that the scientific and academic community should invest more effort in developing the relative technology, in order to provide parts of low cost and thus make the fabrication of a solar vehicle for every day use viable.

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