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Solar powered cars - a review

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Solar powered cars - a review.

P.O. Babalola [1], O.E. Atiba[1]

[1]Mechanical Engineering Department, College of Engineering, Covenant University, Ota, Ogun-State, Nigeria
Corresponding Author: phillip.babalola@covenantuniversity.edu.ng

Abstract-
The world population is increasing and so is the demand for transportation. The commonest of the means of transportation has been the automobile. And while the automobile industry is growing proportionally with population increase, there are still many problems with managing the causes of the pollution by automobiles. Hence, to cater for the needs of the society and still protect our environment, researchers have been seeking alternative sources to power transportation with little or no harmful emission. Suggested forms of energy for automobiles would be ones that are sustainable over the years. There are various available options of solar-powered vehicles which produces electricity through photovoltaic cells without any form of harmful waste to the atmosphere. In developing solar cars in particular, some discovery has been made in the aspect of effectively capturing, converting, and storing the solar energy to make it competitive with the conventional fossil fuel drive vehicles. This review covers the advancement and gaps in existing literature in the modulus operand of solar cars.

Keywords: Solar car, automobile, photovoltaic cell, solar-powered

1. Introduction

In literature, several kinds of research have been done on solar-powered cars to ensure that it is an economically viable alternative car and could offset conventional cars. Of present, solar cars are yet to be sold as practical day-to-day transportations used for transportation. They have remained primarily as the demonstration vehicles and engineering experiments due to state-of-the-art technologies needed to produce them on a large scale. Most times solar car projects are committed to institutions sponsored by government agencies or groups that build them for solar race competitions [1]. The major limitation of having solar cars as commercial vehicles are associated with power density, cost, and design considerations. While it may be impossible to deal with the drawbacks of solar-powered cars, some approaches such as solar parks, lightweight power storage, and integrated PV's (Photovoltaic) have been developed to increase the energy input that can enable prolonged mobility of this alternative car [2].

Any vehicle that is propelled by an electric drivetrain taking power from a portable solar photovoltaic module or rechargeable battery is a solar-powered vehicle. Solar car, a variant of the solar vehicle is primarily designed to work on power obtained from the sun. A solar-powered car depends on photovoltaic cells to convert sunlight into electricity to run electric motor(s) that later drives the car wheels. In practical terms, the model for the solar car will need to use solar panels to harvest solar energy and store it in a rechargeable battery or auxiliary system that complements the powering of the motor that will propel the wheels of the car. Aside from motor vehicles, PV solar energy has been used to power barbing saloon [3], furnace blower [4], residential apartment, greenhouse fan, wastewater treatment, water pumps, and so on.

1.1 History of solar cars

The history of solar car dates to a tiny 15-inch vehicle model created by General Motors staff, William G. Cobbs in 1955 which was showcased at the Powerama convention in Chicago. The car was named Sun mobile, made of 12 selenium photovoltaic cells and small Pooley electric motor driving a pulley which rotates the shaft of the rear wheel [5]. This first solar car by William G. Cobbs in 1955 was too small to drive as such development met the premier vehicle. In 1958, The International Rectifier Company made the premier solar car that humans could drive. Though this converted vintage model 1912 Baker electric car is shown in Figure 1 was redesigned to have about 10,640 identical solar cells attached to the rooftop to propel it. It had to wait until 4 years later in 1962 to exhibit the invention. In 1977, Professor Ed Passereni from Alabama University put together the Bluebird solar car as a prototype full-scale vehicle. The Bluebird was intended to work from the power of the photovoltaic cells only without the need for a battery. Bluebird was later exhibited in Knoxville, at TN 1982 World's Fair.

Between 1977 and 1980, other improvements had been made to the solar-powered. At Tokyo Denki University, Professor Masaharu Fujita first created a solar bicycle as a 4-wheel solar car which was made from two solar bicycles. By the same token in 1979, Englishman Alain Freeman invented the 3-wheeler solar-powered car with a solar panel on the roof (Fig. 2). In 1980, Arye Braunstein and his engineering colleagues at Tel Aviv University in Israel created a solar car. This solar car incorporated solar panels located on the hood and on the roof of a Citicar having 432 cells that created 400 watts maximum power. The car also used eight (8) batteries of 6 volts each to store the photovoltaic energy.

Figure 1: The picture of the second solar car built in 1958 (Source: Automo Story, 2014)

Figure 2: Freeman's solar car built in 1979 (Source: Automo Story, 2014)

The partnership between Hans Tholstrup and Larry Perkins in 1982 resulted in a solar-powered racecar that recorded the first person to undergo intercontinental travel in a solar-powered car, from Perth to Sydney, Australia. Tholstrup later went on to establish the World Solar Challenge in Australia. In 1984, Greg Johanson and Joel Davidson built the Sunrunner solar race car. The Sunrunner set an official record in Bellflower, California of 24.7 mph with a battery. While in 1986, at the Mojave Desert of California, Solely Solar Powered Vehicle reached a final top speed of 41 mph without using a battery and setting

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another Guinness Book of World Records. Later the GM Sunraycer in 1987 completed a 1,866 mile (3003 km) trip with a regular speed of 42 mph. Since 1987 to date, many solar cars have been invented at universities for competitions such as the Shell Eco-Marathon while there are also a few commercially available solar cars such as the Venturi Astrolab.

1.2 21st Century solar cars

The advocacy for solar cars particularly the commercial ones are driven by four main factors: sustainability, efficiency, convenience, and economy [6]. A few prototypes of solar cars driven solely by photo-energy of the sun have been invented and tested since the 1970s to 1990s. None of these solar vehicles were intended for day-to-day transport but for vehicle demonstration and engineering exercises thereby enabling students and investigators to improve on energy input saving and automotive applications [7]–[9].

Technological efforts have made significant improvements in advanced cars and competitions have further pushed the advancement of solar-powered cars like Sunswift (I-V) and Nuna (1-9) [8]. New solar cars have been built to have improved tyre thread than normal cars to allow for reduced rolling friction. Solar race competitions around the world have allowed for high cost with needs to minimize weight, cut down on friction and aerodynamic losses, and particularly improve on storage capacity for regular operation. The ultimate comparative advantage of solar-powered cars has been electrification. Fleet electrification has been added to 21st driven solar cars with the intent of augmenting torque to and from the powertrain. Hence, solar cars built for commercial purposes are usually made as a hybrid vehicle that uses synergetic power from other sources such as internal combustion engines [10].

Ford and Mazda have extensively explored the possibilities of having solar hybrid vehicles on the commercial scale rather than as concept cars. The Ford Reflex in 2006 has solar panels built into the headlights while solar panels were mounted in the Mazda Senku 2005 platform to support the electric battery. 2008 Cadillac Provoq utilises solar panels for power supplies such as indoor lighting and audio. Although the Reflex, Provoq, and Senku are design vehicles, cars fitted with solar panels could be pacing their entry through the vehicle automotive market while companies are looking to find innovative ways to reduce dependence on fossil fuel automobiles. Venturi, a French automobile maker, declared the unveiling at the Paris Auto Show 2006 of the concept Eclectic platform. The Hybrid blends sun, wind, and battery resources to drive a three-person vehicle for urban driving purposes. Solar panels protect their roofs, with a wind generator collecting electricity on bubbling days. However, the Ventury eclectic (Figure 3) is not limited to 30 miles (48 km/h) of road transport. It begs the question of how convenient solar-powered vehicles are.

Figure 3: Venturi Eclectic Concept Car [8]

Figure 4: All Solar Powered Car [8]

2. Design Concept of Solar Based Automobile

2.1 Operation principle of solar cars

A solar car is made with less complex systems than conventional cars. The solar-powered car has electrical systems, mechanical systems, solar array, and aerodynamics systems. The conceptual design of a solar-powered vehicle is much dependent on the dimension and profile of the mechanical and electrical components of the car design. The general design of the solar car has the chassis on the base designed to cater to the load (electrical, mechanical, and occupant) and top area of the vehicle to accumulate solar panels [5].

2.2 Solar array and power trackers

The solar array created by each cell to form a fabricated solar panel produces a range of millivolts to a few volts of currents above 3 amps at peak sunlight. The number of cells used is dependent on the solar car size and the allowable solar cells per Winston rules. The group of solar cells are then wired in series on a power tracker panel and subdivided into several zones in the car [5].

2.3 Batteries

The batteries of solar cars help in storing solar energy from the solar array and deliver them to the electric motors to use. Storage battery size is dependent on the motor system power efficiency, drive cycle, and vehicle weight. Most of the solar cars use alkali-ion rechargeable batteries such as lithium-ion or nickel-ion cadmium. Also based on weight or watthour requirement, the voltage of the solar car can be computed; for a system of 48 volts, the solar car would need four (4) 12-volts batteries [11].

2.4 Motors and controller

Due to the high maximum efficiency of 80-90%, the DC brush permanent magnet motor is the common primary driver for solar cars. Controllers are what drives a motor and vendors of solar cars have associated controller for each motor.

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2.5 Instrumentation
All specific information needed to control the solar-powered car is derived for the electronic control unit (ECU) which is the engine control box module that accounts for the order of all electrical part control (battery pack, motors, and solar panels) and mechanical actuation (wheels) [12], [13]. These on-board diagnostics (OBD) data gotten from the different system of the solar car is evaluated to optimize the overall performance of the solar vehicle system [14], [15].

2.6 Steering and suspension
Front-wheel steering gets a lot of priority for solar cars as stability and overall safety are provided on the anterior part of the vehicle. Also, suspensions of the solar-powered vehicle are designed to be soft and rigid in order to protect the car parts and particularly keep solar PV array from jolting out during wavering motion [16].

2.7 Tyres and hubs
The right tyre suspension cannot be taken for granted as the effect of rolling resistance that can impact the available energy need for traveling. The right tyres for solar cars happen to be the ones with high pressures and thin but less susceptible to going flat. Bridgestone Ecopia tyre is made for solar cars of the modern age cause the test rules have certified them to offer the least resistance and minimal lubrication to solar vehicles [5].

3. Solar Car Model

3.1 Solar cars powertrain
The powertrain of solar-powered cars includes electrical subsystems such as the embedded powertrain controllers, storage systems, power electronics, and electronic continuously variable transmissions [17]. The aim of the powertrain is to enable energy transfer from the source of the power (battery or solar PV panel) to the driving loads (wheels) with the least loss of energy needed for the driving cycle. The powertrain configuration is dependent on the solar vehicle module which essentially determines the well-to-wheel efficiency. The goal of the powertrain control is to have an efficient solar car with a good driving performance at maximum fuel economy, minimum emissions, and least system cost. The electronic control unit (ECU) is the intelligent electric module that controls the flow of electrical current from both the rectifier (that normalises the mechanical power from transmission wheel) and battery. The ECU compose of electronic memory units for storing data, computing units, control wires for data exchange, and sensing units for signal acquisition. Electric motors in solar cars are powered through a solar photovoltaic solar panel that charges the battery. The electric motor is coupled to the transmission. The drive train is the electric motor system that receives the mechanical power of the wheel torque and regulates the mechanical power for wheel controller and transmission. Subsequently, the combination of the powertrain configuration shown in Figure 5 the flow of power depending on any driving parameters.

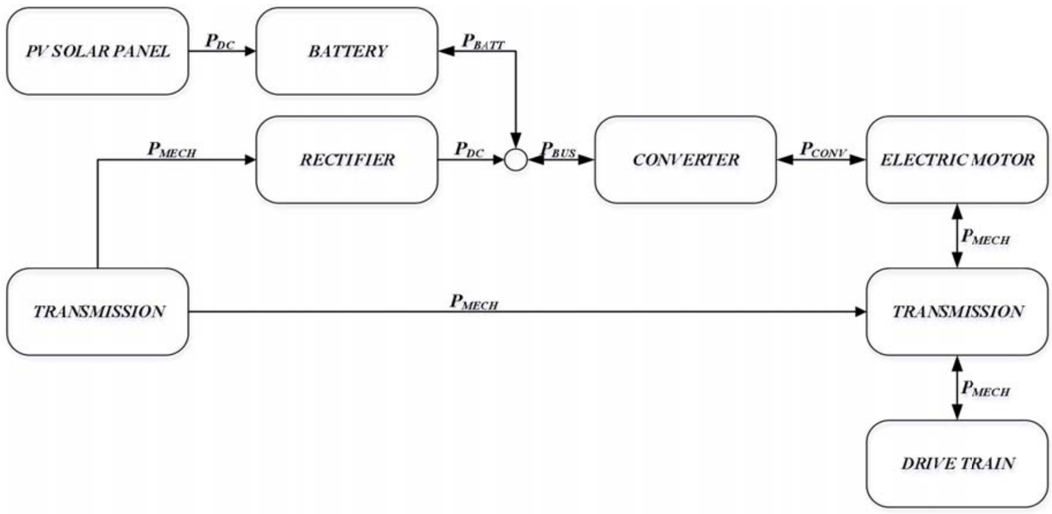

Figure 5: Basic powertrain configuration of solar-powered cars

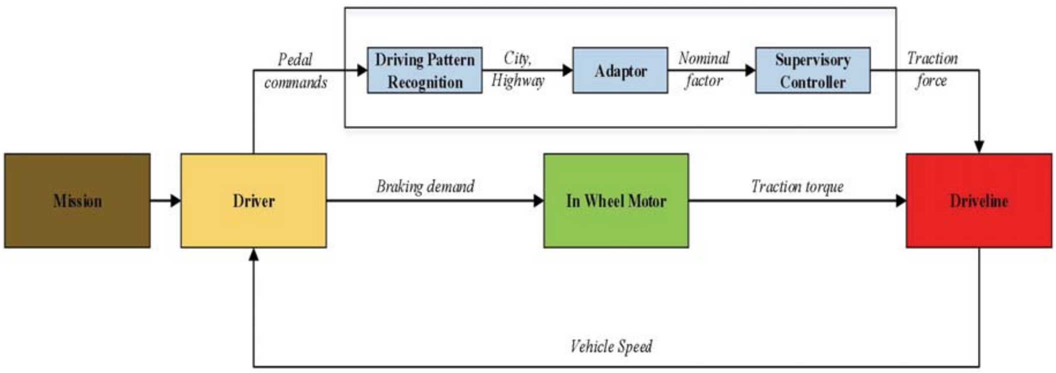

Figure 6: Block diagram indicating the driving control system of solar cars

3.2 Driving parameters

The solar car control module determines the engine, clutch, pump, final control, and wheels rotational dynamics while offering roll and aerodynamic power [18].

Braking

Solar cars have In Wheel electric Motors (IWM) on the wheels for regenerative braking. As in the case of hybrid electric vehicles, solar cars have torque split systems from the driveline thus making the engine control module employ the IWM torque to charge the storage battery of the car. This occurs when wheel-motors retains a negative torque, relative to the normal braking intensity, thereby to converting part of the vehicle kinetic energy into chemical energy in the battery. The initiation of this driving mode is subject on the current battery State-of-Charge, to prevent battery overcharge [19].

Cruising (coasting)

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In the condition where solar vehicles are operating with the throttle pedal off, the wheel motors are simulated to be sometimes redundant or operate in order to retain small negative torque to be absorbed by the battery [20].

Backing motion

Backing motion mode is important for IWM to detect the wrong operation and make effective energy efficiency by keeping the car operating on either the solar PV module or car battery [18].

Bending

Sensors of solar cars are usually actuated to detect bends by proper differentiation of right to left wheel rear wheel turns when supplying either positive or negative torque. This sensor also provides the steering angle needed for the car [21].

Car stop

The full integration of vehicle stop in solar cars is not as important as it may be with other hybrid electric vehicles that permit null (neutral) gear during cases of traffic. Nevertheless, solar cars have both driveline electric motor not delivering positive or negative torque in standing conditions [1].

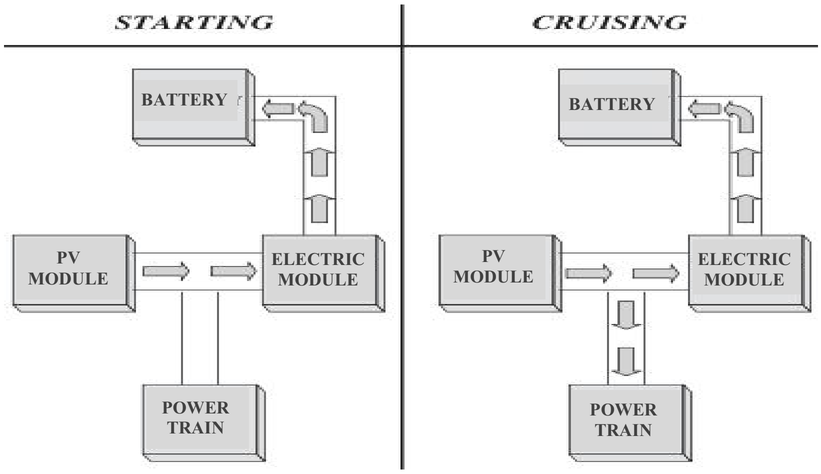

Figure 7: Powertrain operation modes for starting and cruising of solar cars

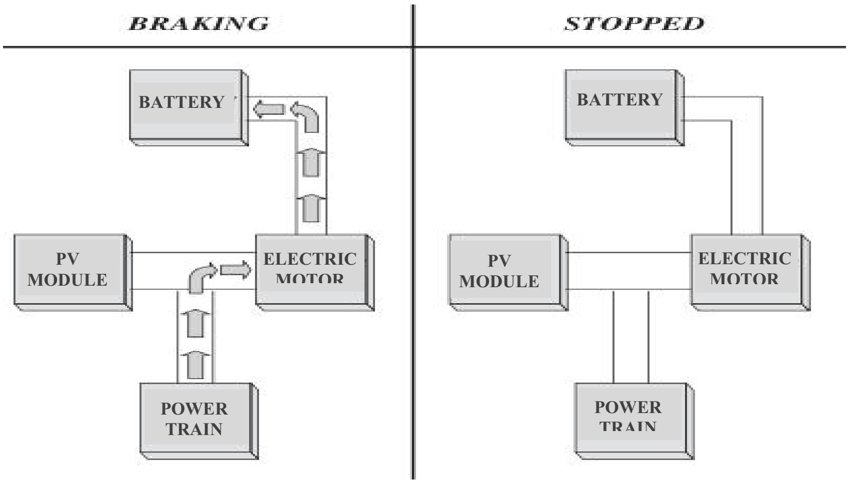

Figure 8: Powertrain operation for braking and stopped modes of solar cars

Figure 9: PrISUm Solar Car [22]

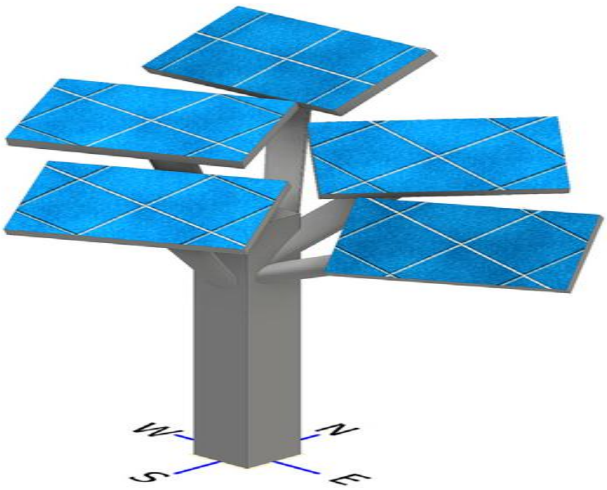

Figure 10: A rendered image of solar energy tree [25]

4. More lineage

Increasing solar car lineage may involve using lightweight materials [22] as exhibited in PrISUm Solar Car (Figure 9). Also, using an aerodynamically shaped body to reduce air drag and efficiently cool solar panel of the vehicle [23] is necessary. Installation of power-efficient battery with additional solar trailer [24] will be helpful. Furthermore, energy trees (Figure 10) may be provided at an interval that is less than 150 km for charging solar-powered cars and traditional electric vehicles. These would be useful for peak usage, few cloudy days, and night trips. Excess power from the energy trees could be used for charging cell phones, street light, neighbouring house, or connected into the national grid as it is done elsewhere. In Nigeria context, the following cities may serve as locations for energy trees: Lagos, Abuja, Ibadan, Kano, Onitsha, Port Harcourt, Ilorin, Lafiagi, Bida, Jos, Bauchi, Lafia, Makurdi, Azare, Potiskum, Maiduguri, Minna, Kaduna, Zaria, Funtua, Gusau, Marafa, Sokoto, Katsina, Kafanchan, Ijebu-Ode, Ore, Ondo, Owo, Lokoja, Benin City, Sapele, Warri, Uyo, Calabar, Enugu, Abakaliki, Aba, Owerri, Akure, Abeokuta and Gboko. With the algorithm proposed by Hasicic et al. [25], distance route estimation of solar vehicle vis-à-vis solar irradiation data is now possible.

5. Conclusion

The question of whether solar-powered cars can be practical is getting better answers. Solar cars powered only by sunlight and attaining average speeds of 80 km/h have been in existence for over a decade. So, it would be a question of why one needs a 2500 kg machine driven by polluting fuels to get to work and return each day. The real deal with the solar car then is how to achieve both high motor output and high aerodynamic efficiency with high-efficiency PV cells on a car that weighs less than 300 kg. With efficient batteries and energy management strategies, solar cars would soon be commonplace. An increase in fuel costs and advances to photovoltaic technology may contribute to the transition from prototypical application to commercial transport use of solar vehicles. Moreover, the use of solar cars would be a universal automobile solution just as the sun is.

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Reference

[1] Pudney, P., and Howlett, P. (2002). "Critical Speed Control of a Solar Car," *Optim. Eng.*, vol. 3, no. 2, pp. 97–107, doi: 10.1023/A:1020907101234.
[2] Jaffery, S.H.I. (2014). "The potential of solar powered transportation and the case for solar powered railway in Pakistan," *Renewable and Sustainable Energy Reviews*, vol. 39. Elsevier Ltd, pp. 270–276, Nov. 01, doi: 10.1016/j.rser.2014.07.025.
[3] Edeghe, M.B., and Babalola, P.O. (2018). "200 Watts Portable Solar Generator for a Typical Barbing Salon," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 413, no. 1, doi: 10.1088/1757-899X/413/1/012029.

[4] Babalola, P.O., Bolu, C.A., Inegbenebor, A.O., Oyedepo, S.O., Kilanko, O. and Adeyemi, G.A. (2019). "Application of solar photovoltaic system to power air blower and mixing mechanism in a tilting furnace," *World Rev. Sci. Technol. Sustain. Dev.*, vol. 15, no. 2, pp. 160–169, doi: 10.1504/WRSTSD.2019.099372.

[5] Gupta, A.K. (2018). "Today ' s Need & Importance Role of Solar based Automobile System," vol. 5, no. 5, pp. 26–30.

[6] Betancur, E., Osorio-Gómez, G., and Rivera, J.C. (2017)."Heuristic optimization for the energy management and race strategy of a solar car," *Sustain.*, vol. 9, no. 10, pp. 1–12, doi: 10.3390/su9101576.

[7] Wellington, R.P. (1996). "Model solar vehicles provide motivation for school students," in *Solar Energy*, vol. 58, no. 1–3, pp. 137–146, doi: 10.1016/0038-092X(96)00073-4.

[8] Rizzo, G. (2010)."Automotive applications of solar energy," in *IFAC Proceedings Volumes (IFAC-PapersOnline)*, vol. 43, no. 7, pp. 174–185, doi: 10.3182/20100712-3-DE-2013.00199.

[9] De Silva, J. G. and Svenson, R.(1993) "Tonatiuh, the Mexican solar race car: A vehicle for technology transfer," in *SAE Technical Papers*, doi: 10.4271/931797.

[10] Simpson, A. G., Walker, G.R., Greaves, M. C., Finn, D. A. and Guymer, B. D. (2002). "The UltraCommuter : a viable and desirable solar-powered commuter vehicle," *Australas. Univ. Power Eng. Conf. AUPEC'02*.

[11] Guzzella, L. and Sciarretta, A. (2005). *Vehicle Propulsion Systems: Introduction to modeling and optimization*. Springer Berlin Heidelberg

[12] Arsie, I., Di Martino, R., Rizzo, G. and Sorrentino, M. (2008). "Energy Management for a Hybrid Solar Vehicle with Series Structure," *IFAC Proc. Vol.*, vol. 41, no. 2, pp. 3362–3367, doi: 10.3182/20080706-5-kr-1001.00571.

[13] Marano, V., Medina, H., Sorrentino, M., and Rizzo, G. (2013)."A Model to Assess the Benefits of an After-Market Hybridization Kit based on Realistic Driving Habits and Charging Infrastructure," *Source SAE Int. J. Altern. Powertrains*, vol. 2, no. 3, pp. 471–481, doi: 10.2307/26169030.

[14] Rizzo, G. (2013) "Automotive Applications of Solar Energy," doi: 10.3182/20100712-3-DE-2013.00199.

[15] D'Agostino, M., Naddeo, M. and Rizzo, G. (2014). "Development and validation of a model to detect active gear via OBD data for a Through-The-Road Hybrid Electric Vehicle," in *IFAC Proceedings Volumes (IFAC-PapersOnline)*, vol. 19, no. 3, pp. 6618–6623, doi: 10.3182/20140824-6-za-1003.01166.

[16] Sharma, A. K. G., Yadav Abhinav, S. and Saharyar, M. (2018). "Today's Need & Importance Role of Solar based Automobile System," *IJIRST-International J. Innov. Res. Sci. Technol.*, vol. 5. Available: www.ijirst.org.

[17] Katrašnik, T. (2009). "Analytical framework for analyzing the energy conversion efficiency of different hybrid electric vehicle topologies," *Energy Convers. Manag.*, vol. 50, no. 8, pp. 1924–1938, doi: 10.1016/j.enconman.2009.04.016.

[18] Arsie, I., Di Martino, R., Rizzo, G. and Sorrentino, M. (2008). Energy Management for a Hybrid Solar Vehicle with Series Structure, vol. 41, no. 2. IFAC.

[19] Maia, R., Silva, M., Araújo, R. and Nunes, U. (2015)."Electrical vehicle modeling: A fuzzy logic model for regenerative braking," *Expert Syst. Appl.*, vol. 42, no. 22, pp. 8504–8519, doi: 10.1016/j.eswa.2015.07.006.

[20] Arsie, I., D'Agostino, M., Naddeo, M., Rizzo, G., and Sorrentino, M. (2013). "Toward the development of a through-the-road solar hybridized vehicle," in *IFAC Proceedings Volumes (IFAC-PapersOnline)*, vol. 46, no. 21 PART 1, pp. 806–811, doi: 10.3182/20130904-4-JP-2042.00157.

[21] Hasicic, M, Bilic, D. and Siljak,H. (2017). "Criteria for Solar Car Optimized Route Estimation," *Microprocess. Microsyst.*, vol. 51, pp. 289–296, doi: 10.1016/j.micpro.2017.05.005.

[22] Howell, E., Neal, D., Kieffer, D. (2018). Changing the paradigm of transportation: Lightweight composites used in solar car in intercollegiate competition, *Reinforced Plastics*, Volume 62, Number 4

[23] Vinnichenko, N. A., Uvarov, A.V., Znamenskaya, I.A., Ay, H, Wang, T. (2014). Solar car aerodynamic design for optimal cooling and high efficiency, *Solar Energy* 103, 183–190

[24] Kasti, N.A., (2017). Ranges of applicability of a solar-battery car with single and double solar-trailers, *Solar Energy* 144, 619–628

[25] Dey, S., Lakshmanan, M.K., Pesala, B. (2018). Optimal solar tree design for increased flexibility in seasonal energy extraction, *Renewable Energy* 125, 1038-1048.