Impact Factor (SJIF): 5.301

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444

Volume 7, Issue 3, March-2020

Important Aspects for the Design of Battery Powered Electrical Car

Bhavesh C. Raval[1] ,Mahendra G. Mathukiya[2] , Devendra R. Parmar[3]

[1]*Electrical Department, C.U.Shah College of Engineering & Technology, C.U.Shah University*
[2]*Electrical Department, C.U.Shah College of Engineering & Technology, C.U.Shah University*
[3]*Electrical Department, C.U.Shah Institute of Diploma Studies, C.U.Shah University*

Abstract ***—since the invention of automobile technology, the car development has always caught the attention of the society. The various models have been emerged based on the availability of the fuel type and technology of the respective period in history. At present, the world is facing the challenge to reduce the carbon emission in the environment and control the temperature rise. Further, the goal to provide the clean technology and optimize the non conventional technology has always been the preference of researchers and also supported by political will of various countries across the world. This paper provides the insights to the important aspects to be considered while a novice person starts to develop a design of battery powered electrical car.***

Keywords- Battery Technology; Lead Acid Battery; Lithium Ion battery; Aerodynamic Forces; Computational Fluid Dynamics; Battery Management System; Super Capacitors.

I. INTRODUCTION

The solar powered car, hybrid car and battery powered electrical car are the technologies on which the development of current and future car is focused. The diesel and petrol fuel based car model has served the society for a longer duration. As the technology is changing it is important to become aware with the important aspects of the new technology and its merger required with the present technology. This paper represents these necessary aspects to be considered while designing a car on battery powered model.

II. MATHEMETICAL MODEL OF FORCE AND BATTERY PARAMETERS

The total force on a car model consists of acceleration (F_A),air drag(F_D) and rolling resistance(F_R)[11].The dragging force on the car plays a major role while in motion and offers a significant portion up to 60% of total force. The equation necessary to calculate force and power are given below. The description of the parameters is provided in table 1.

2.1. Force and Power Calculation

$$F_T=F_A+F_R+F_D \quad (1)$$
$$F_A=ma^2 \quad (2)$$
$$F_R=\mu mg \quad (3)$$
$$F_D=1/2\ C_D\rho Av^2 \quad (4)$$
$$P_S=F_Tv \quad (5)$$
$$P_B=(P_S/v)\eta_M \quad (6)$$

Table 1: Specification of Force Power and Battery Parameters

Force Parameters	Power Parameters	Battery Parameters
F_T : Total Force on Car (N)	μ :Co-efficient of rolling resistance	I_L : Load current (A)
F_A: Acceleration Force (N)	g: Gravitational acceleration (m/s^2)	V_{OC}: Open circuit voltage (V)
F_R: Rolling Force (N)	C_D: Co-efficient of air drag force	Vd: Voltage drop at resistance R_0 (V)

F_D: Drag force due to air (N)	ρ: Air mass density (Kg/m^3)	R_S: Series resistance of the battery (Ω)
m: Mass of car (Kg)	A: Cross section area of Car (m^2)	P: Power supplied by battery (W)
a:Linear Acceleration (m/s^2)	v: Velocity of vehicle (m/s)	Q_{dis}: Total charge dissipated(C)
P_S: Shaft power of motor (W)	P_B :Battery delivered power (W)	t: Time (Second)
η_M : Efficiency of Motor	V_t: Terminal voltage (V)	SOC: Status of Charge

2.2. Battery Power Calculation

The mathematical model of battery is important for simulation and design purpose. TheThevenin's model of battery is taken as reference as shown in figure 1[11].The description of parameters is given in Table 1.

$$I_L= [(V_{OC}-V_d) -\{[(V_{OC}-V_d)^2 - 4R_SP \}^{1/2}] / 2R_S \quad (7)$$

$$V_t=V_{OC}-I_LR_S-V_d \quad (8)$$

$$Q_{dis}=(I_L-I_{CH})t \quad (9)$$

$$SOC(new)=SOC(old) - Q_{dis}/C \quad (10)$$

$$V_{OC}=1.4667SOC - 11.0233 \quad (11)$$

$$V_d=0.086\ SOC-0.011 \quad (12)$$

$$R_S= -\ 0.0531SOC +0.066 \quad (13)$$

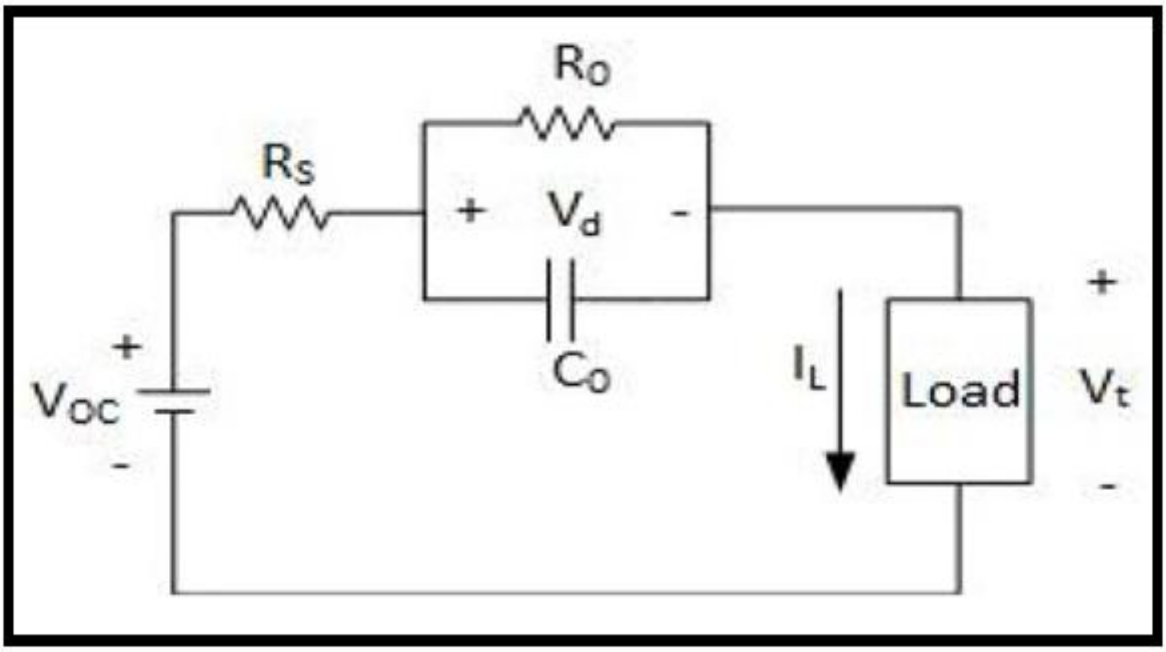


Figure 1. Thevenin's Battery Model[11]

III. AERO DYNAMIC FORCE ANALYSIS TOOLS

Aero dynamic forces play major role in providing resistance and consuming power when speed of car is above the range of 40 kmph. The various factors those needs to be considered for analysis purpose include the drag, lift, Vortex, and wake region etc. As the good amount of complexity is involved for the assessment of these factors, the various analysis tools are necessary for the solution. The Computational Fluid Dynamic Study (CFD) is utilized for this purpose by various softwares. According to Oleg Zikanev the Computational Fluid Dynamics (CFD) is defined as: "A set of numerical methods applied to obtain approximate solution of problems of fluid dynamics and heat transfer[6]."

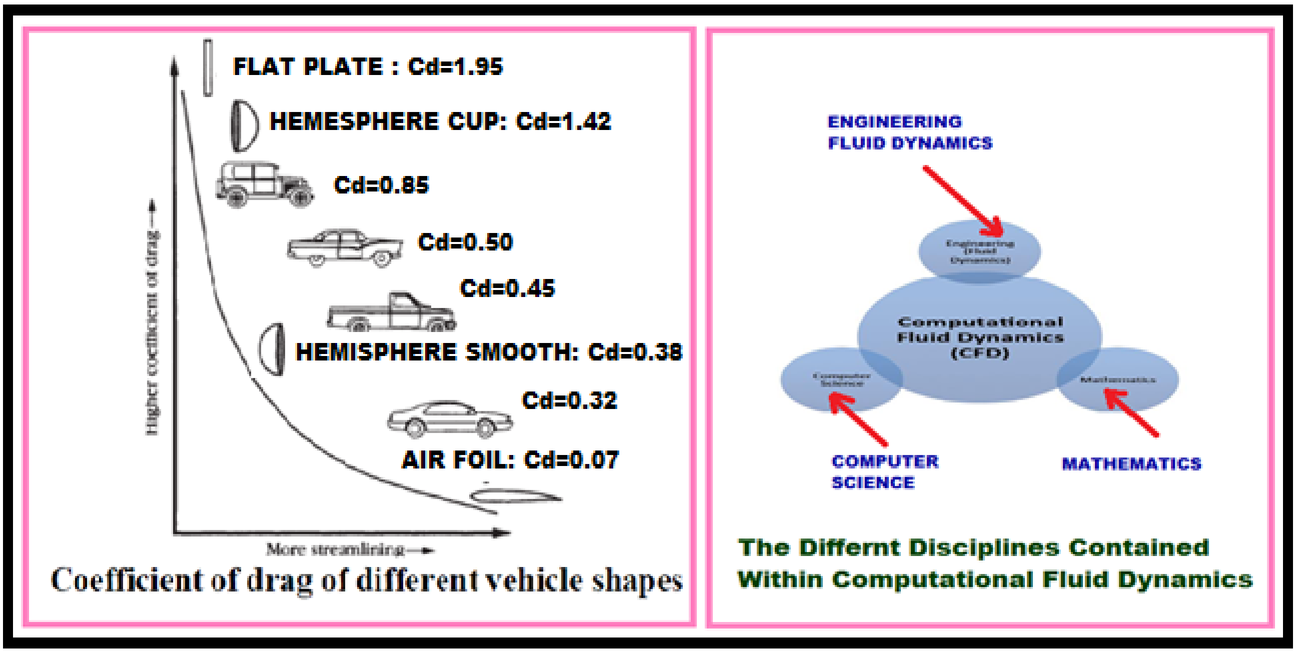


Fig. 2. Various values for Co-efficient of Drag (Cd) and Elementary Blocks of Computational Fluid Dynamics

The various analysis software used for Aero dynamic force calculations include ANSYS^R Workbench , Star CCM+^{R}, Autodesk^R Simulations, Simflow, Featflow, Autodesk^R Inventor etc[7]. Among these, the ANSYS^R Workbench and Star CCM+^{R} are widely used. ANSYS^R Workbench is mostly used by Academic purpose while industry prefers to work on Star CCM+^{R}[7]. The lateral symmetry and polyhedral meshing element is usually applied in both ANSYS^R and Star CCM+^{R} to develop a computer aided model of a car. The shape of the car also plays important role to reduce the co-efficent (Cd) of aero dynamic drag as shown in figure 2 above.

IV.BATTERY TECHNOLOGY AND IMPORTANT ASPECTS

The battery are classified as SLI (Starting, Lighting and Ignition) battery and Deep Cycle battery from application point of view; the former is designed to supply the current over a long period of time whereas later has shorter life span. High Power to weight ratio, high specific energy density , shorter charging time , higher coulomb efficiency ,higher no of charge/discharging cycle and safety of operation are some of the expectation from the battery used for automobile electrical car application. The present trend of batteries available for car application includes:

- Lead Acid Battery
- Ni-Cd Battery
- Ni-MH Battery
- Zebra Battery
- Lithium Ion Battery

The important specifications of various batteries are listed in the table 2 given below :

Table 2. Specification of Various Batteries

Battery/Specification	Efficiency(%)	Specific Energy(Wh/kg)	Distance per charge (km)	Discharge Cycles
Lead Acid Battery	70-75	30-40	30-80	300-600
Ni-Cd Battery	70-90	60-80	-	2000
Ni-MH Battery	60-70	30-80	200	-
Zebra Battery	-	120	-	1500-3000
Lithium Ion Battery	99	150-250	320-480	4000

4.1. Lithium Ion Battery

Among the above listed battery, the Lithium ion battery along with its variants is most preferred now a day. The salient features of the lithium ion batteries are listed herewith. The drawback of traditional lithium-ion batteries includes sensitivity to temperature, low temperature power performance, and performance degradation with age. Due to the volatility of organic electrolytes, the presence of highly oxidized metal oxides, and the thermal instability of traditional lithium-ion batteries pose a fire safety risk if punctured or charged improperly [11].

The salient features of Lithium ion batteries include:

4.1.1. Quick Charging

It can reach up to the 80 percent of charge within 30 minutes. The researcher in Singapore has developed a battery in 2014 that can recharge up to 70 percent within 2 minutes.[11]

4.1.2. Connectors

The charging power can be connected to the car in two ways. The first is a direct electrical connection known as conductive coupling. The second approach is known as inductive charging. A special 'paddle' is inserted into a slot on the car. The paddle is one winding of a transformer.

4.1.3. Variants

Variants of Lithium Ion batteries include:

- Lithium Manganese Battery
- Lithium Cobalt Battery
- Lithium Iron Phosphate Battery ($LiFePO_4$)
- Lithium NMC Combine Battery (NMC)

Lithium manganese battery has moderate heat built up tendency when delivering current up to 20-30 A. However, Lithium Cobalt battery is not thermally stable in nature. The phosphate in Lithium Ion helps for thermal stabilization and provides better heat stability and over charging capability but suffers from self discharge issues. Combining nickel and manganese enhances each other's strengths, making NMC the most successful Li-ion system and suitable for EV power trains. These batteries are currently in high demand and provide the high specific energy and excellent thermal characteristics [10].

V.BATTERY MANAGEMENT SYSTEM

Battery management system is important aspect for those batteries which are prone to thermal run away. It includes the monitoring and control of charging/discharging of battery. The other function includes the potential monitoring of a battery as a whole and individual cell equalization, fast charging etc. The micro controller, semi conductor switches and gate driver circuits along with sensors are used for battery management system. Normally constant current–constant voltage (CC-CV) method for charging is recommended by the manufacturer as shown in figure 3. The present trend is to use fast charging methods of Lithium Ion battery. The Super capacitors are also used in combination with the batteries.

The important terms related to battery management system are :

- Status of Charge (SOC)
- Status of Health (SOH)
- Energy Efficiency
- Depth of Discharge (DOD)

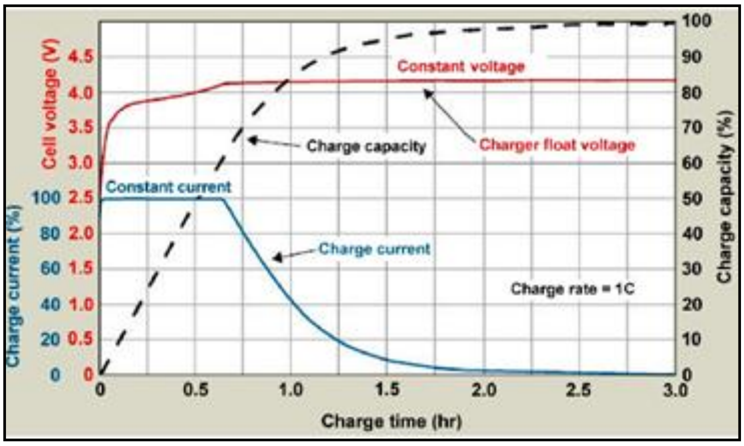


Figure 4. Constant Currnet and Constant Voltage Charging Approach[10]

5.1. Functional Block of Battery Management System

The important aspects of battery management system are listed in table 3 given below. The algorithm is set for master controller and slave control to monitor the status of the battery for high power and complex system. The master controller monitors the status of the battery and instructs the slave controller to deliver the current to motor accordingly; based on the time and charge available.

Table 3. Components of Battery Management System and its Function [10]

Component of BMS	Functional Detail of Each Block
Measurement block	It captures individual cell voltages, battery current and battery voltage at different points of battery bank, along with ambient temperature and convert into digital values
Battery Algorithm Block	It determines the SOC and SOH using battery measured variables
Capability Estimation Block	It provides information to Engine Control unit regarding status of charge/discharge.
Cell Equalization Block	It compares the difference between cell voltage, determines the highest and lowest cell voltage and apply the cell balancing techniques.
Thermal Management Block	It compares the various temperatures reading from measurement block, asses the condition of cooling and heating, gives command to cooling actuators if available and send emergency signal of engine stop in worst case condition.

5.1.1. SOC and DOD :

The SOC for lead acid battery and DOD for Lithium Ion battery is shown in table 4. The SOC and DOD are complimentary terms.

Table 4. SOC and No Load Voltage for Lead Acid Battery / DOD and Discharge Cycles for Lithium Battery

SOC% Lead acid	Voltage (volt)	SOC% Lead acid	Voltage (volt)		DOD % (NMC/$LiFePO_4$)	Discharge Cycle	DOD (NMC/$LiFePO_4$)	Discharge Cycle
100	12.7	40	11.9		100	300-600	40	1000-3000
80	12.42	20	11.58		80	400-900	20	2000-9000
60	12.20	10	11.31		60	600-900	10	6000-15000

It is clear from the table that the SOC of Lead Acid battery below 60% is not recommendable where as DOD for Lithium Ion type battery above 40% is not recommendable.

VI.SUPER CAPACITORS

The super capacitors are having the capability of fast charging and discharging. Besides the ordinary dielectric between plates one membrane is used in the super capacitors which separates the cat ion(+) and an ion(-) of chemical used. The electrolyte chemical is used for creating the pseudo capacitance. The energy storage capability of these capacitors is 10 to 100 times higher and higher temperature band in the range of -20 ^{0}C to +70 ^{0}C. The charge/discharge cycles of a typical Lithium Ion battery lies in the range of 500-10000 cycles where as for super capacitors 100,000 to 1000,000 cycles[13]. Area of application of super capacitors includes mobile charging, Automobiles, Buses, Trains and Elevators etc. The capacitors are used in such applications for regenerating breaking or instant supply of energy. Categorically the super capacitors are divided into two types:

- Double Layer Capacitor
- Pseudo Capacitor

The double layer capacitor is created by inclusion of Helmholtz layer inside between the two electrodes and stores the charge electro statically. In the Pseudo Capacitor the charge is stored electro chemically. In conjunction with chemical battery the super capacitors provide immediate voltage buffer to compensate for quick changing power loads. The Ultra battery available in market consists of lead acid battery in conjunction with super capacitors [13]. With this combination the charge/discharge rate, efficiency, cycle life and overall performance of battery is improved. The various aspects of super capacitors are shown in figure 5 below.

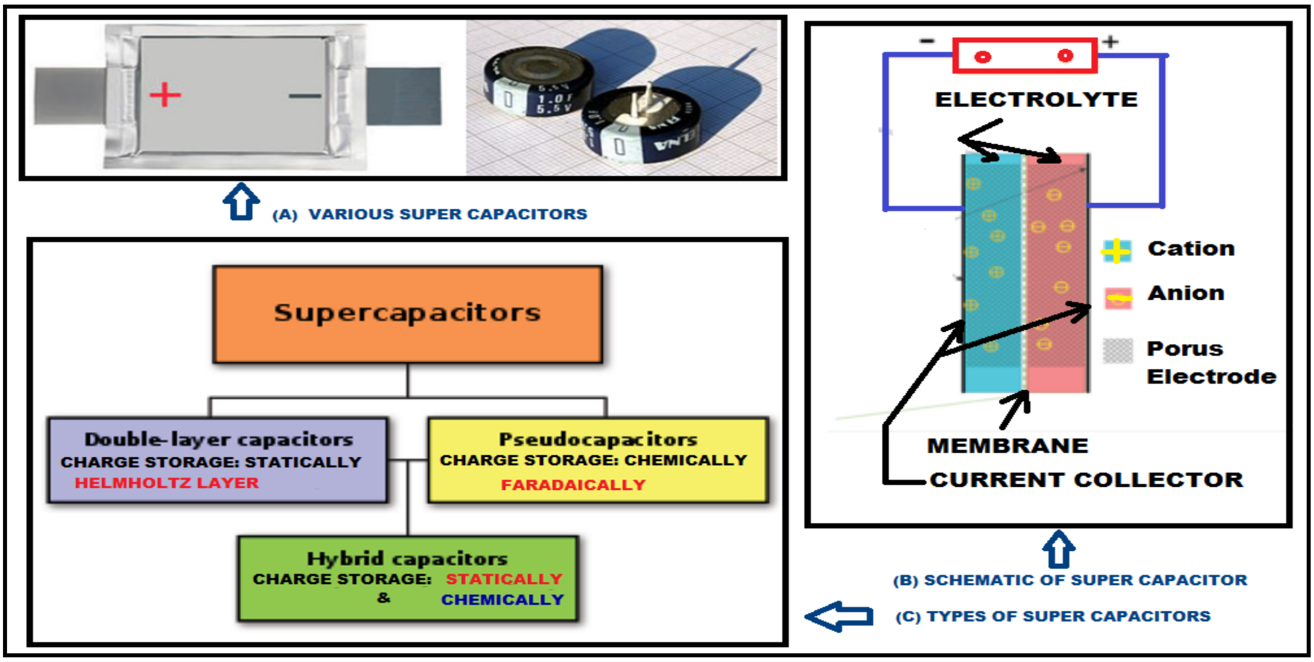


Figure 5. Various Aspects of Super Capacitor

VII.ELECTRICAL MOTORS

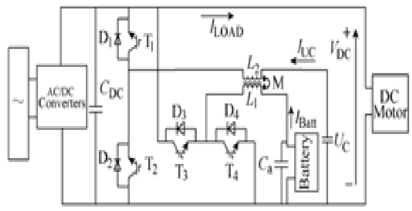
Various motors such as DC Series, BLDC, Gear DC motor can be utilized depending upon power and force requirement. The rating varies from few kW to few tens of kW. The present technology has also worked with the option of 3 phase induction motor with suitable inverter [15]. When low power rating is required, the DC motors are suitable. Present technology for long distance range of battery powered vehicle have trend to use induction motors. Therefore, a suitable inverter technologies are also required to match with the application.

VIII. DC TO DC CONVERTER TOPOLOGY

When DC to DC converter topologies are used, the various aspects covered for optimum operation include cost, conversion efficiency, controllability and complexity of control. Some of the recent topologies include Zero Voltage Switching (ZVS) and Zero Ripple Switching with Integrated Magnet Technology[14].The control strategy used include Artificial Neural Networks, Fuzzy Logic etc. Some of the recent topologies proposed by researchers is shown in figure 6 along with operation mode of hybrid energy system [14].

The operation mode of hybrid energy storage system

Working mode	Power source	Power flow	Operation mode
Parking charging mode	AC power	Battery and super capacitor	Buck
Constant speed mode	Battery	DC	Boost
Acceleration mode	Super capacitor	DC motor	Boost
Braking mode	Braking energy	Battery and super capacitor	Buck
Super-capacitor charging mode	Battery	Super capacitors and DC motors	Boost or buck



Topology of the hybrid energy storage system

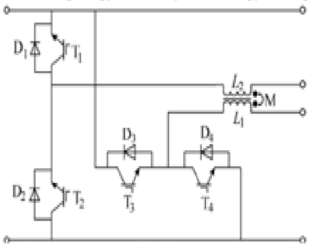

Topology of DC/DC converter with integrated magnetic structure

Figure 6. Recent DC to DC Converter Topology and its Operation Mode In Hybrid Energy System

IX. CONCLUSION

This paper has combined the crucial techniques, mathematical models, recent trends and practices on a common platform to develop a battery powered electrical car model. However, several other practical aspects are necessary to develop a real car model but the review of this paper shall be useful to obtain a macroscopic view to the beginner for development of an electrical car model. Based on this the one shall be able to decide the area in which one needs to go into the details and acquire the skill necessary to develop the real time model as a beginner.

REFERENCES

[1] D.T. Abinesh, B. Kalidasan,"A Review on Solar Electric Vehicle",Imperial International Journal of Eco-friendly Technologies,Vol.-1,Issue-1,pp. 80-83,2016

[2] Tarik M. Abdullah Khan, Srea Rahman, Solar Car, BRAC University,Dhaka, Bangladesh

[3] Abhinay Chaturvedi, Kirti Kushwaha,"Solar Powered Vehicle", International Journal of Electrical and Electronics Research, Vol.3, Issue 2, pp. 270-273,April-June 2015

[4] Dipen V.Shah, Riddhi M.Shah, Solar Car, C.U.Shah University, 2019

[5] Gokul Krishnan Rajamani, CFD Analysis of Air Flow Interaction in Vehicle Platoons, RMIT University, August 2006

[6] Vikas V.Chaurasiya, Deepak B. Kushwaha, Mohd. Raees, "Aerodynamic Analysis of Vehicle Using CFD", International Journal of Recent Trends in Engineering & Research, Volume 03, Issue-3,pp. 131-137, March 2017

[7] Adil Loya, Ammar Iqbal, Muhhamad Tauseef Nasir, Hasan Ali, Muhhamad Zia Ullah Khan, Muhhamad Imran, "Automotive Aerodynamics Analysis Using Two Commonly Used Commercial Software", Scientific Research Publishing, pp. 22-32, January 2019

[8] Saud Hassan, Sajid Abdullah, Aerodynamics Investigation of Rear Vehicle (Backlight Angle),Teesside University,April 2014

[9] https://en.wikipedia.org/wiki/Electric_vehicle_battery

[10] Yu Miao, Patrick Hynan, Annete von Jouanne, Alexandre Yokochi, "Current Li-Ion Battery Technologies in Electric Vehicles and Opportunities for Advancement", *MDPI transectioins on Energies*, pp. 1-20, March 2019

[11] Abdullah Al Mahmud, Asif Zaman, Imran Bin Jafar, Mosaddequr Rahman, " Simulation and Analysis of Battery Performance of a Solar Car Using a Model Implemented in Simulink",IEEE *Proceedings of International Conference on Electrical Information and Communication Technology, pp. 471-474, 2015*

[12] Anirudh Kumar, Shubham Jangid, Ishan Patiyat, Joydeb Roychowdhury, "Intelligent Battery Management System for Runtime optimization of an Electric car",*IEEE proceedings on International Conference on Information Communication and Embedded System,2013*

[13] https://en.wikipedia.org/wiki/Supercapacitor

[14] Xiangyang Xia, Xinxin Zhao, Heqing Zeng, Xiaoyong Zeng, "A Novel Design of Hybrid Energy Storage System for Electric Vehicles", Chinese Journal of Electrical Engineering, Vol. 4, Issue 1, pp. 45-51, March 2018

[15] Bhavesh C. Raval, Riddhi M. Shah, Dipen V. Shah, Bindi V. Patel, "Dual Charge Battery Operated Car for Campus Monitoring", International Journal of Modern Trends in Engineering and Research, Vol. 7, Issue 2, pp. 25-29, February 2020