# A Study of Performance of HEV Run By Hybrid Power Sources by using Supercapacitor Bank, Ultrabattery And Fuel Cell

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## ABSTRACT

*Recently a growing interest on utilizing renewable and green energy has been motivated by rapidly increasing oil prices, limited fossil fuel reserves and growing environmental green awareness. Since the energy density of supercapacitor is less but power density is thousand time more than that of battery, ultrabattery is a hybrid energy-storage device, which combines the best of asymmetric supercapacitor and battery in a unit cell without any extra electronic controls. Fuel cell can also be used as an electric source. This paper deals with model of HEVs run by hybrid power sources in which a supercapacitor bank, ultrabattery and fuel cell are used as main source, a dc link and supercapacitors as transient power source, the comperative analysis of performance of models of HEV is simulated with the help of MATLABSIMULINK software. comparative performance of HEV is discussed in detail. This sutudy in fact gives an idea to construct supercapacitor pack of appropriate power and energy density for HEV and minimize the dependence on battery.*

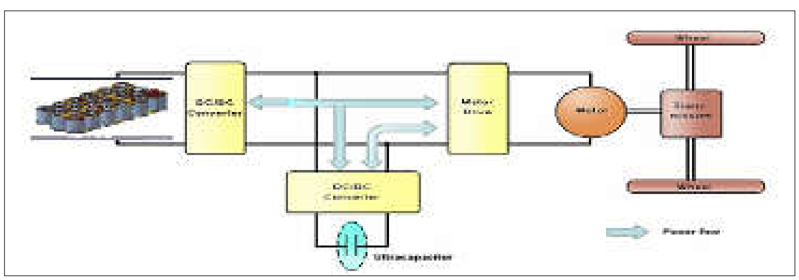
***KEYWORD**: Supercapacitor; Ultrabattery; Fuel cell, DC/DC converter; HEV*

## INTRODUCTION

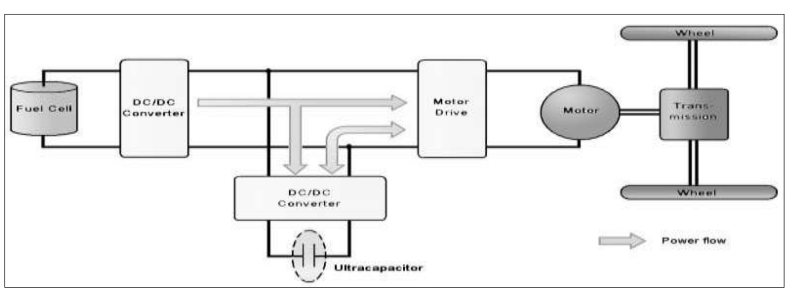
The present rate of reliance and consumption of fossil fuels for electrification or transportation is $10^5$ times faster than the rate at which they are being created by natural sources.In fact,19$^{th}$ and 20$^{th}$ century were the century of the steam engine and internal combustion engine respectively and 21st century will be definetly the century of the battery, supercapacitor, ultrabattery and fuel cell[1]. Fuel cells (FCs) produces an electrical energy from an electrochemical reaction between a hydrogen-rich fuel gas and an oxidant. They convert hydrogen, or hydrogencontaining fuels, directly into electrical energy plus heat through the electrochemical reaction of hydrogen and oxygen into water. Supercapacitors are able to hold much greater charge and able to release an enormous amount of power in a very short time it has an excellent power density, 1000 times more than some batteries, very good load characteristics with efficiency of almost 100% compared with batteries that only have 50-60% but have low energy density, up to 300 times less than batteries. Aging is not an issue for the supercapacitor it is not subjected to over voltages, too large currents and too high temperatures, its lifetime can be up to almost 80 years. It is also possible to deep cycle it more than $5x10^6$ times, very rapid charging. But there is some limitation of low energy density, low voltage, high self discharge.[2] Whereas batteries can release steady voltage for a longer period of time. An ultrabatery is a recent technology which is the combination of supercapacitor and battery in single unit cell. The present paper is a comparative study of performance of HEV model run by (i)Ultrabatery (ii)Combination of supercapacitor and ultrabattery (iii)Combination of supercapacitor and fuel cell In this study the MATLABSIMULINK is used for fabrication of model.

## MODEL OF HEV

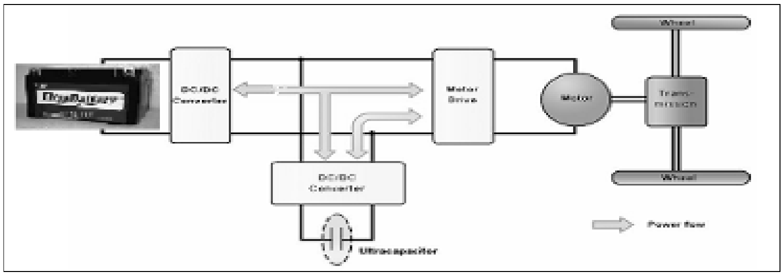
The Model of HEV run by supercapacitor, battery, ultrabattery and fuelcell is shown in the fig(1,2,3). In HEV applications, a supercapacitor unit will have a voltage of 200-400 V, this resulting in connecting numbers of cells. To predict the behavior of the supercapacitor voltage and current during transient state, physics-based dynamic models are needed to account for the time constant due to the double-layer effects in the supercapacitor. In the model of HEV run by supercapacitor supercapacitor is used for peak power and finaly the vehicle run by supercapacitor bank. In sueprcapator based HEV the supercapacitor electrode can act as a buffer to share the discharge and charge currents with the lead-acid negative plate and thus, prevents it being discharged and charged at the high rates. Ultrabattery has a life cycle four times longer, 50% more power, about 70% cheaper than the batteries currently used in HEVs. The model of HEV where Ultrabattery is main source and supercapacitor for peak power is shown in the fig(2). The model of HEV run by Fuel cell is shown in fig.(3) in which fuel cell is used as main power source and supercapacitor for peak power. A fuel cell is an electrical battery cell, which unlike storage cells can be continuously fed with a fuel so that the electrical power output is sustained indefinitely. Because hydrogen and oxygen gases are electrochemically converted into water, fuel cells have many advantages over heat engines. These include high efficiency, virtually silent operation and, if hydrogen is the fuel, there are no pollutant emissions. If the hydrogen is produced from renewable energy sources, then the electrical power produced can be truly sustainable. Enhancing the output efficiency and improving the performance of fuel cell are among main research topics [6,7]. When an electrical load is attached across the anode and cathode of the fuel cell, a working voltage is produce between 0.5 and 0.8 volts, depending on the cell operation conditions. To create practical working voltages, individual cells are stacked together in series to form a fuel cell stack. The actual open circuit voltage of the cell is less than the ideal voltage because of different loss mechanisms[8,9].



Fig(1) HEV run by supercapacitor bank




Fig(2) HEV run by ultrabattery and supercapacitor




Fig(3) HEV run by fuel-cell and supercapacitor

## MATHEMATICAL CALCULATION

To select the supercapacitor the useful variables are maximum Voltage $V_{SC\max}$, nominal voltage $V_{SCnom}$, minimum allowable voltage $V_{SC\min}$, current requirement $I_{SC}$ , power requirement $P_{SC}$, time of discharge $t_d$, and time constant, to estimate the minimum capacitor $C_{SC\min}$ , an energy equation can be written as

$$W_{SC} = \frac{1}{2}\left(V_{SCnom}^2 - V_{SC\min}^2\right) = P_{SC} t_d \tag{1}$$

Where, $W_{SC}$ = energy of supercapacitor, If in the vehicle acceleration the voltage drop form the $V_{Scnom}$ to $V_{SC_{max}}/2$ and the power density of supercapacitor is of the order of $5x10^3$ W/kg with discharge time 10 sec the supercapacitor voltage a time t.

$$V_{SC} = V_{SCnom}\sqrt{1-\left[1-\left(\frac{V_{SCnom}}{V_{SC\min}}\right)^2\right]\frac{t}{t_d}}, \tag{2}$$

and supercapacitor current at time t

$$i_{SC} = \frac{P_{SC}}{50\sqrt{1-\frac{3t}{4t_d}}} = \frac{5x10^3}{50\sqrt{1-\frac{3}{4}}} = 200A \tag{3}$$

The minimum capacitance of supercapacitor for HEV can be calculated as

$$C_{SC} = \frac{2P_{SC}t_d}{5\sqrt{V_{SC_{nom}}^2 - V_{SC_{min}}^2}} = \frac{2x5x10^3x10}{5\sqrt{(240)^2-\left(\frac{240}{2}\right)^2}} = 481.14F \tag{4}$$

The number of suprcapacitor for supercapacitor bank and ultrabattery given by equation[4]

$$n = \frac{\frac{2P_{SC}t_d}{C_{SC\min}} \pm \sqrt{\left(\frac{4p^2t^2}{C_{SC\min}^2} + \frac{4V_{SC\min}^2 P_{SC}^2}{i_{SC}^2}\right)}}{2V_{SC}^2} \tag{5}$$

The same calculation is useful for battery, ultrabattery. It gives a rough ideas about their capacitance, power, current output and how many number of these devices required for a particular HEV.

The current of fuel cell can produce equals current density times of the fuel cell's active area. The current density of the fuel cell varies from 0 to 1.2 A per square-centimeter.

Increasing the active area can enlarge the current producing capability of the fuel cell. The power of fuel cell given by the relation[10,11,12,13,14,15,16,17]

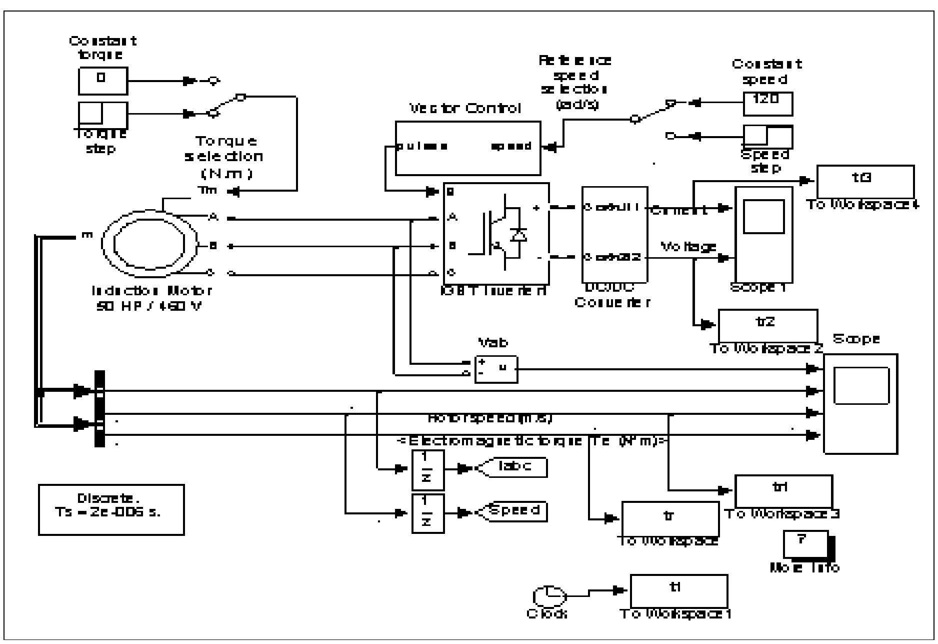
$$P_{FC} = \frac{V}{1000\eta_t\eta_m}\left(Mgf + \frac{1}{2}\rho_a C_D A_f V^2\right)kW \qquad (9)$$

M = total mass of the vehicle, V= vehicle speed,f = rolling resistance coefficient, $\rho_a$ = air density, $\eta_m$= Motor efficiency $\eta_t$ = transmission efficiency $C_D$ = is aerodynamic drag coefficient that characterizes the shape of the vehicle and $A_f$= vehicle frontal area. In this example, about 25kW are needed at 130 km/h of constant speed driving. In this design, the fuel cell motor power is expected to support the vehicle driving at around 150 km/h on a flat road and 100 km/h on a 5% grade road.The parameter of the vehicle are, Mass= 1500kg, Vehicle speed =150km/h, Rolling resistance coefficient $\rho_a$= 1.205, Vehicle frontal area $A_f$= 2 $m^2$, Aerodynamic drag coefficient $C_D$= 0.3, Rolling resistance coefficient f = 0.01. , Motor efficiency $\eta_m$= 0.95, transmission efficiency $\eta_t$ = 0.9. The fuel cell power needed is:

$$P_{FC} = \frac{150}{3.6x1000x0.9x0.95}\left(1500x9.8x0.01 + \frac{1}{2}x1.205x0.3x2x\left(\frac{150}{3.6}\right)^2\right)kW = 37.75\text{kW}$$

### MATLAB SIMULINK MODELING OF VEHICLE

Common parallel configurations of HEV with supercapacitor pack, ultrabattery and fuel cell with superacapacitor banks are shown in Fig.(2),(4), and (6) respectively. The parallel capacitance handles shortduration, high-current events, smoothing the demand on the energy storage devces. These configurations often require a supercapacitor bank with a voltage comparable to that of the other energy storage bank. In some cases, the supercapacitor voltage operates in a range between the other energy storage voltage and some maximum charge voltage, supplying current to traction motor or other load when its voltage is higher than that of the battery. A low-current charging circuit may allow energy transfer between the battery/ultrabattery and supercapacitor,[18].

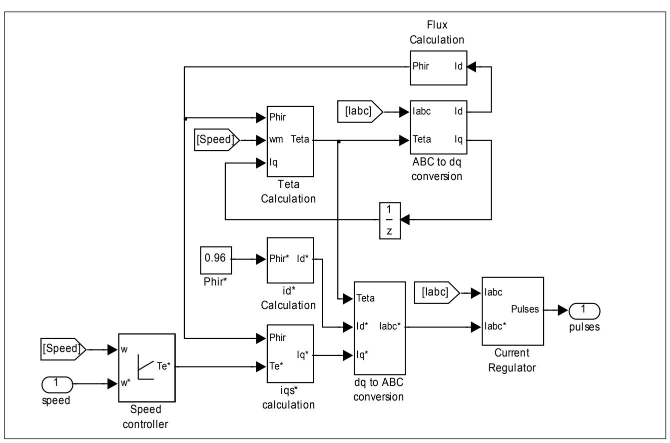


In either case, the supercapacitor bank needs to be precharged to a minimum operating voltage. In more advanced implementations, DC/DC converters manage multi-directional power transfer between the supercapacitor/ultrabattery and supercapacitor, and traction motor in buck-boost operation. The ultracapacitor operating voltage is less constrained in these implementations, but it is still likely to be in the range of the supercapacitor/ultrabattery voltage to improve conversion efficiency. When vehicle start during buck mode all the energy released from supercapacitor/ultrabattery/fuel-cell the supercapacitor provide peak power to start the vehicle while the vehicle finaly run by the constant energy from supercapacitor/ultrabatery/fuel-cell. In the case of supercapacitor pack a switching devices inserted between the supercpapcitor bank and other supercapacitor. [19].The series configuration places a low voltage supercapacitor model in series with the ultrabattery. During braking, the DC/DC controller disconnects the supercapacitor/ultrabattery/fiel-cell and only the supercapacitor is used to recapture energy. Acceleration can be serviced by the supercapacitor/ultrabattery/fuel cell alone or these devices together with supercapacitor. Only fuel cell work along one direction and can not capture energy during vehicle running/breaking. MATALAB SIMULINK model HEV using ultrabattery is shown in fig (11), their parameter is also listed. [20]

Dimention for 12 V, Capacitance = 6.5 Ah ,Height 110mm, Width 87mm, Length 150mm,Weigh=1500kg, Cycle>$2x10^{5}$,Voltage = 240Model = < 5H.P., Operating voltage = 240V, Friction(F) = 0.005752(Nms), Capacity of Suprcapacitor = 2600F, Nominal Power($P_n$) =3730w, Nominal frequency($f_n$) = 50Hz, Rotor resistance($R_r$) = 1.083Ohm, Rotor Inductance($L_r$) = 0.005974H, Mutual inductance(Lm) = 0.2037 H, Inertia(J) = 0.02 $kgm^{-2}$.

Fig(11) MATLABSIMULINK Model of HEV

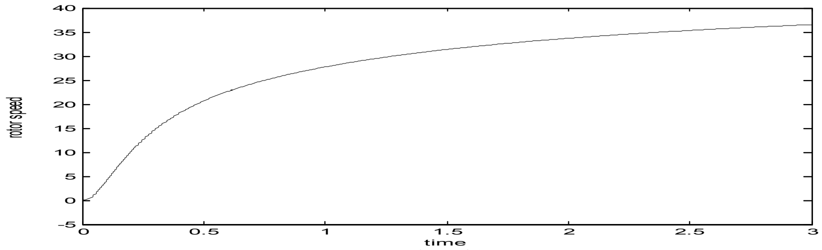
In the modeling the maximum speed to the vehicle restricted to 120 km/h by the use of velocity controller shown in fig(12). the modeling the DC/DC converter is also represented in fig(8). The power and voltage output is also represented in fig (9) and fig(10).



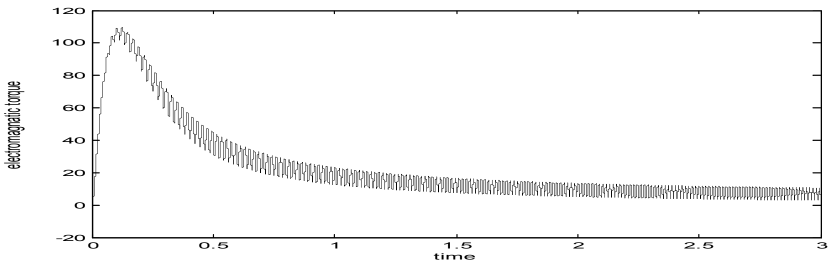

Fig(12) SIMULINK Model of velocity controller

## RESULT

The result of rotor speed and torque obtained by running the vehicle with combination of supercapacitor bank, ultrabattery and fuel cell with supercapacitor. The peak power provide to the vhehicle during vehicle starting is shown in fig(12). The output of voltage is also in fig(11).In this work, the used ultrabattery made by lead-acid battery of 240V and asymmetric supercapacitor of capacity 2600F. The rotor speed and electromagnetic torque obtain by MATLABSIMULINK model is shown below.

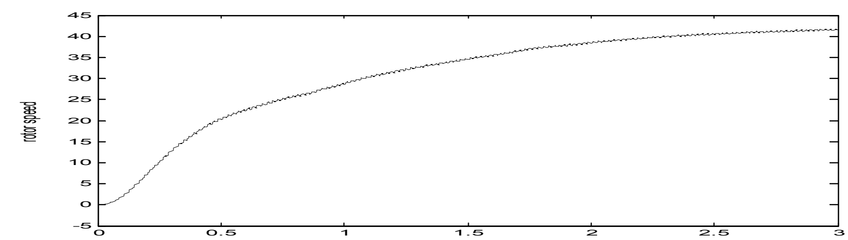



a. Rotor speed (m/s)

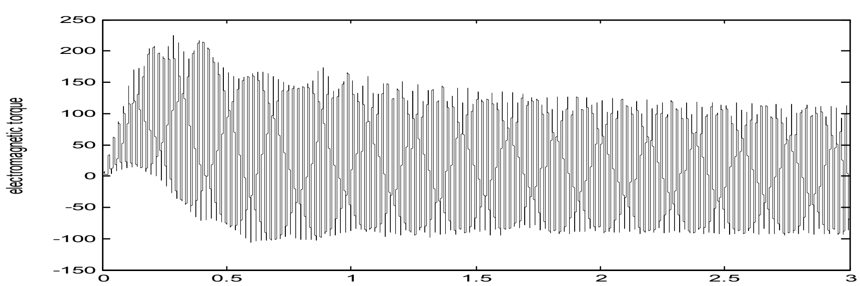



b. Electromagnetic torque (Nm)

Fig.15 Output of HEV run by Ultrabattery

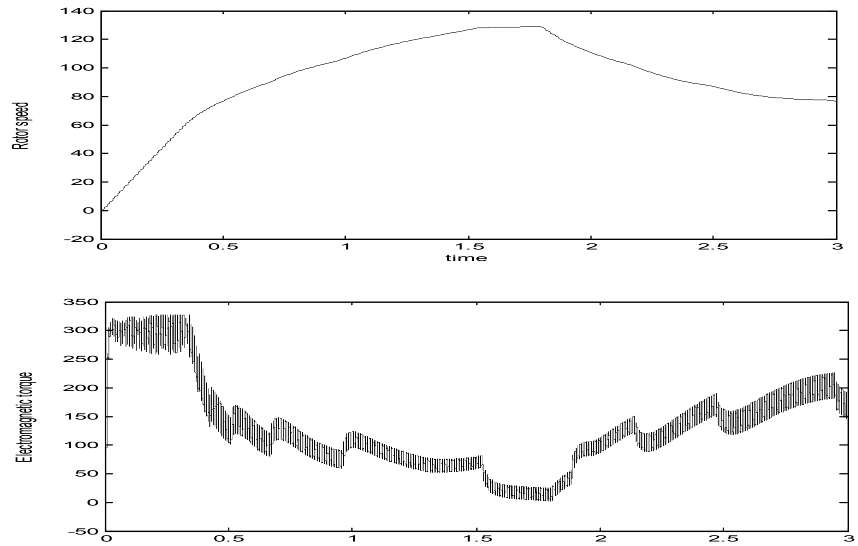



a. Rotor speed (m/s)

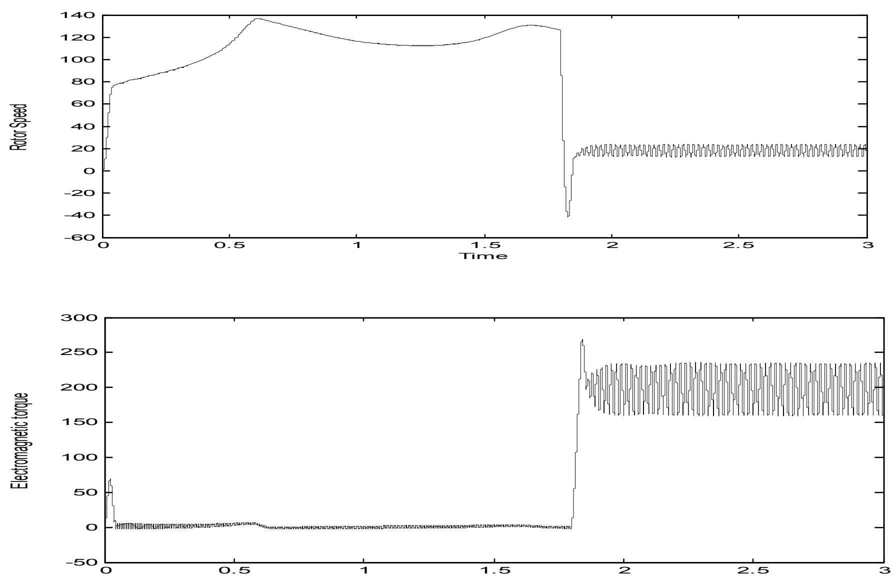



b. Electromagnetic torque (Nm)

Fig. (16 )Output of HEV run by supercapacitor[21,22]




Fig(17) Output of HEV in combination with combination of supercapacitor and ultrabattery battery




Fig(18) Output of vehicle by fuel cell

Fig(15a,16a,17a,18a)shows the variation of rotor speed with tme for the HEV run with supercapacitor, ultrabattery combination of ultrabattery with supercapacitor and fuel cell respectively.and fig(15b,16b,17b and18b) represent the variation of electromagnetic torque of HEV run by same component .In fig15(a&b) when vehicle run with ultrabattery the electromagnetic torque increases become constant after small instent, the roter speed increases and become constant.Fig16(a&b) shows when vehicle run with supercpapcitor only while there is rotor speed comparable to output of ultrabattery, but it required repetitive charging of supercapacitor for this and it gives fluctuating torque. Fig17(a&b) shows when vehicle run with combining supercapacitor and battery with buck boost DC/DC converter as torque increases vehicle start running with constant speed but torque goes to low after short time about 2 to 3 second during boost mode vehicle acquire next peak power hence electromagnetic torque again increases. This continue procedure give smooth running of vehicle. In the case of fuel cell Fig18(a&b) vehicle there is non regenerative breaking vehicle operate only in boost mode because in buck mode fuel cell can not be charged. It require hydrogen and oxygen gase for next refilling. To acquire high voltage more number of fuel cell connected in series so it become very heavy, the torque is very low for same rotor speed after few second when supercapacitor realease their power the electromagnetic increases very rapidely but at this time the rotor speed goes down,

## SUMMARY

This is a compression of performance of HEV when it run with supercapacitor, ultrabattery, fuel cell the other supercapacitor connected here with buck boost DC/DC converter. The result shows that vehicle run with ultrabattery and supercapacitor is more efficience that other two mode. In the case of fuel cell because of heavy mass and larger size the efficiency is less. All these modeling give a novel ideas about pollution free HEV there is need of active research in this field for better performance to save the environment..

## REFERENCES:


[1] Dhameja, Sandeep *"Electric vehicle battery systems" British Library Cataloguing-in- Publication Data Copyright © by Butterworth–Heinemann* (2002)

[2] www.batteryuniversity.com, 2004

[3] H. Douglas, P. Pillay *" Sizing ultracapacitors for Hybrid Electric Vehicle"* 0-7803-9252-3/05/$20.00©2005 IEEE.

[5]. L.T. Lam, R. Louey *"Development of ultra-battery for hybrid-electric vehicle applications" Journal of Power Sources* **158** 1140–1148 ( 2006).

[6] B. Delfino, F. Fornari, "Modeling and control of an integrated fuel-cell wind turbine system", IEEE Power Tech. Conference Proceeding, Bologna, Vol.2, 23-26 June 20

[7] J. Correa, F. Farret, L. Canha, M. Simoes, "An electrochemical-based fuel cell model suitable for electrical engineering automation approach", IEEE Transaction on Industrial Electronics, Vol. 51, issue 5, Oct. 2004.

[8] L.Y. Chiu and B. M. Diong, "An improved small signal model of the dynamic behavior of PEM fuel cells," IEEE 38th IAS Annual Meeting, vol. 2, pp. 709-715, Oct. 2003.

[9] J. T. Pukrushpan, H. Peng, and A. G. Stefanopoulou," Simulation and analysis of transient fuel cell system performance based on a dynamic reactant flow model," Proc. of ASME IMECE'02, 2002.

[10] V. Di Dio, D. La Cascia, R. Liga, R. Miceli, Member IEEE: "Integrated Mathematical Model of Proton Exchange Membrane Fuel Cell Stack (PEMFC) with Automotive Synchronous Electrical Power Drive", Proceedings of the 2008 *International Conference on Electrical Machines*, September 2008, page(s) 1-6.

[11] V.Di Dio, A.O. Di Tommaso, R. Miceli, C. Cavallaro, A. Raciti, "Test cycle for the characterization of electrical drives devoted to wheelchair applications", Proceeding of the Fourth IEEE International Caracas Conference on Devices, Circuits and Systems, Aruba, 17-19 April 2002, Page(s):P021-1 – P021-6.

[12] Jeferson M. Corrêa, Felix A. Farret, Luciane N. Canha, Marcelo G. Simões: "An electrochemical-based fuel-cell model suitable for electrical engineering automation approach", IEEE Transactions on industrial electronics, Vol. 51, No.5, October 2004, page(s) 1103-1112.

[13] Jeferson M. Corrêa, Felix A. Farret, Vladimir A. Popov, Marcelo G. Simões: "Sensitivity analysis of the modelling parameters used in simulation of proton exchange membrane fuel cells", IEEE Transactions on energy conversion, Vol. 20, No.1, March 2005, page(s) 211-213.

[14] M.J. Khan, M.T. Iqbal: "Dynamic modelling and simulation of a fuel cell generator", "Fuel Cells" 2005, 5, No.1, page(s) 97-99, 101-104.

[15] Correa J.M., Farret F.A., Gomes J.R., Simoes M.G., "Simulation of Fuel-Cell Stacks Using a Computer-Controlled Power Rectifier With the Purposes of Actual High-Power Injection Applications", Transactions on Industry Applications, IEE Volume 39, Issue 4, July-Aug. 2003 Page(s):1136 – 1142.

[16] Brooks N., Baldwin T., Brinson T., Ordonez J., Luongo C., "Analysis Of Fuel Cell Based Power Systems Using EMTDC Electrical Power Simulator", System Theory, 2004. Proceedings of the *Thirty-Sixth Southeastern Symposium* on 2004 Page(s):270–274.

[17] Vincenzo Di Dio et.al. "Vehicles PEM Fuel Cells Power System Mathematical Model for Integrated Design" Proceedings of the 2008 Ever Ecologic vehicle, renewable energy, Monaco, March 26-29, 2009

[18] A.W. Stienecker, M.A. Flute, and T.A.Stuart, "Improved Battery Charging in an Ultracapacitor–Lead Acid Battery Hybrid Energy Storage System for Mild Hybrid Electric Vehicles," in Proc. *SAE World Congress*, Detroit, Michigan, USA, 2006.

[19] P.C.K. Luk and L.C. Rosario, "Power and Energy Management of a Dual- Energy Source Electric Vehicle – Policy Implementation Issues," in Proc. *International Power Electronics and Motion Control Conference, IEEE*, pp. 1-6,Shanghai, China, 2006.

[20]Allan Cooper *Project Coordinated by: The European Advanced Lead Acid, Battery Consortium,17a Welbeck Way, London W1G 9YJ, UK*.