Comparative Study on Various KERS

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Abstract— **Conservation of natural resources has become a necessity in today's world, especially in the new technology. In the automotive industry, maximum energy is lost during deceleration or braking. This problem has been resolved with the introduction of regenerative braking. It is an approach to recover or restore the energy lost while braking. Kinetic Energy Recovery Systems (KERS) is a type of regenerative braking system which has different approaches to store and reuse the lost energy. This paper mainly highlights the different ways of recovering energy using flywheel, batteries or super capacitors, hydraulic or hydro-electric actuators. It also gives an overview of what system is preferred where and why.**

Index Terms—**Batteries, Flywheel, KERS, Regenerative Braking, Super Capacitors/ Ultra Capacitors.**

I. Thrust And Motivation For This Study

THE initial stimulus for undertaking a study on hybrid vehicles and *KERS* was personal interest. Having learnt the importance of fuel consumption and energy saving systems in automobile industries, this paper is a study on *regenerative Braking* and *KERS* found in *hybrid vehicles*.

II. Introduction

Regenerative Braking

A Regenerative Brake is a Mechanism that reduces vehicle speed by converting some of its kinetic energy into some other kind of useful form of energy – electric current, compressed air [1].

The energy captured is then stored for future use or fed back into a power system for use by other vehicles. For example, electrical regenerative brakes in electric railway vehicles feed the generated electricity back into the supply system [2]. In battery electric and hybrid electric vehicles, the energy is stored in a battery or bank of twin layer capacitors for later use. Other forms of energy storage which may be used include compressed air and flywheels [3].

Regenerative braking practices the principal of an electric motor acting as a generator [4]. It reuses kinetic energy by using its electric motor to regenerate electricity.

Regenerative braking does not dissipate the electric energy as heat and is thus more energy efficient than dynamic braking [4].

KERS

A type of Regenerative braking is called KERS. KERS is an automotive system for recovering a moving vehicle's kinetic energy under braking. The recovered energy is stored in a reservoir (for example a flywheel or a battery or super capacitor) for later use under acceleration [4-6]. Electrical systems use a motor-generator incorporated in the car's transmission which converts mechanical energy into electrical energy and vice versa. Once the energy has been harnessed, it is stored in a battery and released when required [7].

Types of storage devices

There are different type of devices and forms in which the Kinetic Energy lost while braking can be stored. They are:

1) Mechanical KERS
2) Electric KERS
3) Hydraulic KERS
4) Hydro-electric KERS (HESS)

III. Literature review

A. Mechanical storage system

The mechanical hybrid utilizes a rotating mass (or flywheel) as the energy storage device and a variable drive transmission to control and transfer the energy to and from the driveline [4]. The transfer of vehicle kinetic energy to flywheel kinetic energy can be seen as a momentum exchange [4]. Energy is drawn from the vehicle and supplied to the flywheel. In doing this, the speed of the vehicle reduces, (effectively this is braking), whilst the speed of the flywheel increases [5]. At the start of braking the vehicle has a high speed and the flywheel a low speed, giving a certain gear ratio between them [6]. At the end of braking the vehicle has a low speed, and the flywheel a high speed, so the ratio of speeds has changed [6]. Examination of the energy transfer shows that the ratio between vehicle speed and flywheel speed necessarily changes continuously during the energy transfer event [5] [6].

Flywheel based mechanical hybrid systems are not new – systems have previously been developed by the Technical University of Eindhoven and Leyland Trucks amongst others and indeed it is possible to ride on a Flywheel powered tram from Stourbridge junction in England – and a flywheel based system is not without areas requiring focus (most notably the failure modes of the rotating mass and the method of control and transmission of the energy to and from the flywheel.) [7][8]. It has been put into use for Formula 1 cars since the year 2009 [9] [10] [11] [12].

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B. *Electrical storage system*

The well documented electrical hybrid systems utilize chemical batteries as the storage medium and electric motor / generator systems as the energy transfer and control media [13]. KERS components for battery storage systems are: Electric Propulsion Motor /Generator, Power Electronics – Inverter, and the Quad Flywheel Storage [13] [14] [15]. Electric Propulsion Motor and Generator in one are also known as a MGU – Motor Generator Unit [15] [16].

Capacitors are fundamental electrical circuit elements that store electrical energy in the order of microfarads and assist in filtering [16] [17] [18] [19]. The main function of a capacitor is to charge or discharge electricity [19] [20] [21]. Super-capacitors have special features such as long life, rapid charging, low internal resistance, high power density, and simple charging method as compared to capacitors and batteries [22][23].

C. *Hydraulic storage system*

Regenerative braking in vehicles using a variable displacement hydraulic pump/motor together with a hydro-pneumatic accumulator has attracted considerable interest during the last 20–25 years. Such a system is particularly suitable for application in city buses [24] [25] [26] [27] [28] [29].

Despite the significant gains in the efficient use of energy that can be brought about by hydro-pneumatic regenerative braking, its use has not attained great popularity [28] [29] [30]. The added cost, which may represent 10–15% of the total for the vehicle, is undoubtedly a deterrent [31] [32] [33].

D. *Hydro-electric storage system*

Hydraulic accumulator has the characteristics of higher power density and is well suited for frequent acceleration and deceleration under city traffic conditions [32-34]. It can provide high power for accelerations and can recover more efficiently power during regenerative braking [33] in comparison with electric counterparts [35]. However, the relatively lower energy density brings the packaging limit for the increasing accumulator size [35]. For example, *Uzunoglu et al.* [39], *Rodatz et al.* [40], *Thounthong et al.* [41] developed hybrid energy system such as battery/UC, fuel cell/UC, etc. These studies focused on the hybrid energy systems in electric forms, and publications devoted to hydraulic/electric system are relatively scarce, *Ricardo* [38] proposed a combined regenerative-dissipative brake system for a city bus. The regenerative component consists of a fixed displacement hydraulic pump/ motor and a hydro-pneumatic accumulator. *Bozic* [42] introduces hydraulic-electric synergy into hybrid transmission using the free-piston engine technology.

A hydraulic accumulator/battery hybrid energy system, called hydraulic/electric synergy system (HESS), is designed to overcome the drawbacks of existing single energy storage sources used in heavy hybrid vehicles, which adopts hybrid energy structure to combine high power hydraulic accumulator and high specific energy battery together [28]. Figure 1 shows operating modes transition of a hybrid with Hydro-Electric Synergy System.

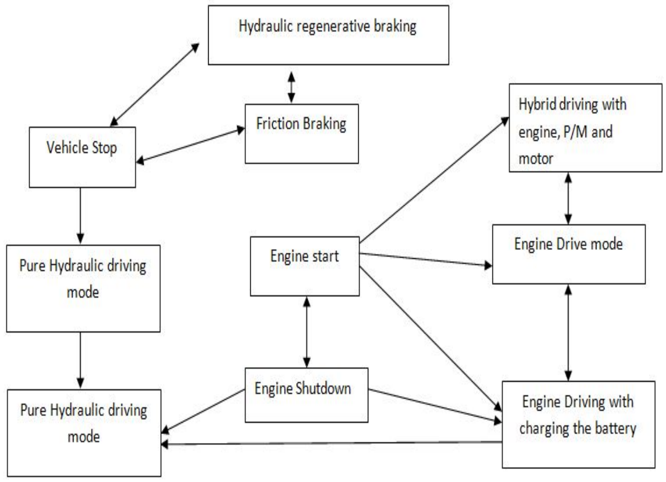

Fig 1: Operating modes transition diagram of hybrid vehicle with HESS.

Hui et al. [43] did a performance comparison study of a battery, a super-capacitor and a hydro-electric storage system which graphically showed that the weight of hydro-electric storage system is significantly lesser than a battery ad a super-capacitor storage system. A study by Jayalakshmi et al. shows that super-capacitors are based on a carbon nanotube) technology. unlike capacitors, Super-capacitors do not have a traditional dielectric material like ceramic, polymer films or aluminum oxide to separate the electrodes but instead have a physical barrier made of activated carbon so that when an electric charge is applied to the material a double electric field is generated which acts like dielectric. The thickness of the double layer is as thin as a molecule. The surface area of the activated carbon layer is extremely large yielding several thousands of square meters per gram. This surface area allows for the absorption of a large amount of ions [37-38]. The charging/discharging occurs in an ion absorption layer formed on the electrodes of activated carbon [38]. According to a study done by *S. Halper et al.* [44], a graphical representation of power densities (along x-axis) and Energy densities (along y-axis) for various energy storage devices such as : capacitors, super-capacitors, batteries, and fuel cells shows that super-capacitors occupy a region between capacitors and batteries [39]. Despite greater capacitance than conventional capacitors, super-capacitors have yet to match the energy densities of mid to high-end batteries and fuel cells [39][40]

This paper looks at other aspects which have not yet been dealt with while considering storage systems for KERS and their future scope. Further studies can be done to improve upon these storage systems.

IV. Analysis

There is always scope for improvement especially in terms of technology. The analysis was done based on the different types of storage system currently in use. It is also an overview of possible alternatives to the commonly used storage devices. It also highlights the drawback of a few KERS.

Instability in voltage can lead to quick wear and tear of the energy storage device. Figure 2 shows that in

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comparison with other storage systems, flywheels offer maximum steady voltage and power level, which is inddependant of load, temperature and state of charge. Second being Lithium ion (Li-ion) battery followed by Nickle metal hydride NiMH nd Lead-acid batteries. Super-capacitors/ ultra-capacitors being the lowest with 30% stability. Reason being that supercapacitors have self-discharge properties. Recent research suggests that this issue might be surmounted[ref.SC a brief overview].

The charge and discharge of electrons cause temperatures to vary in storage devices. There are limitations to the temperature range that these devices can withstand. Figure 3 shows the extensive operating temperature range of these storage technologies. Flywheels again have the biggest temperature withstand range going from -40°C to 150°C as compared to the Lead-Acid batteries which have the least range(-15°C to 50°C). Super-capacitors are the second best at withstanding a large temperature range with a minimum (similar to that of a flywheel) of -40°C and maximum of 70°C could replace the flywheel.

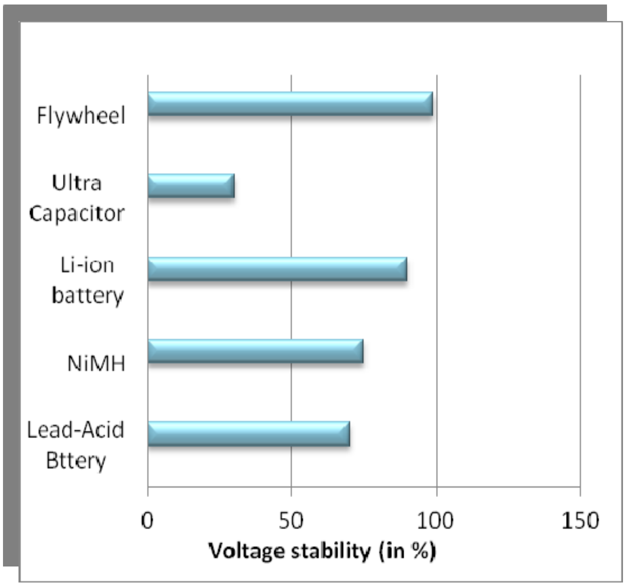

Fig. 2 Voltage stability of different KERS

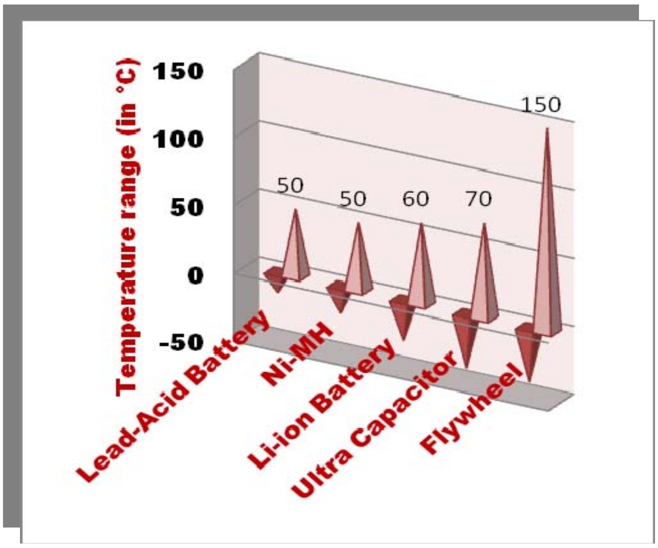

Fig. 3 Temperature of different KERS

Efficiency in storage technologies can be defined as the amount of energy stored by the system to the amount of energy given out or utilized for other use. Figure 4 shows that super-capacitors have maximum efficiency with hydraulic storage devices not being too far from it which is followed b the presently in use mechanical KERS (i.e. flywheel). Batteries have the least efficiency because their discharge rate is faster as compared to the rate at which they charge. Even though super-capacitors have high efficiency, they cannot be used in KERS yet because at constant speed, super-capacitors cannot capture the kinetic energy lost while braking.

Fuel consumption is the main aspect targeted by hybrid cars. This is to conserve and protect the non-renewable and natural resources. It is seen (from figure 5) that 40% of fuel consumption reduction takes place if super-capacitors are prioritized as storage device. Second being flywheel with 27% followed by hydraulic energy system and batteries with 18% and 15% fuel consumption reduction respectively. Batteries contribute least because they have short life and less conversion capacity as compared to other storage devices since their maximum and minimum temperature range is very small.

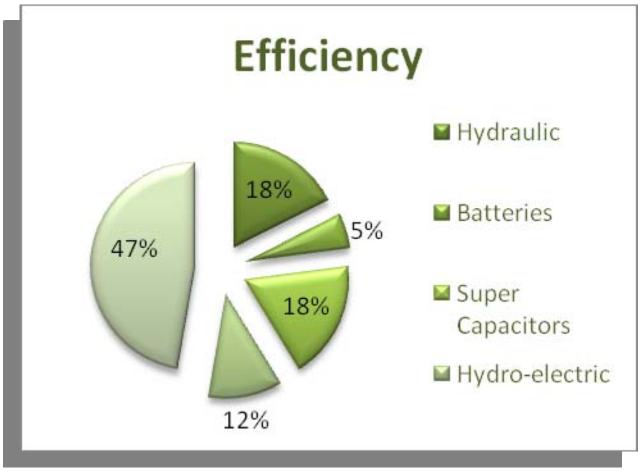

Fig. 4 Efficiency of different KERS

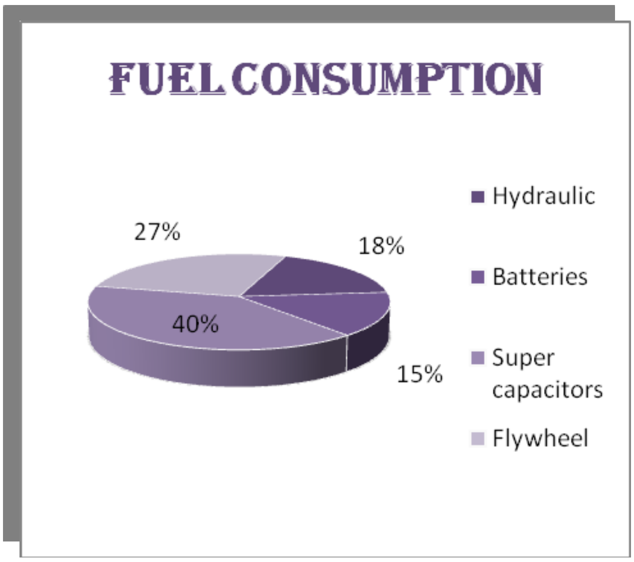

Fig. 5 Comparison of fuel consumption of different KERS

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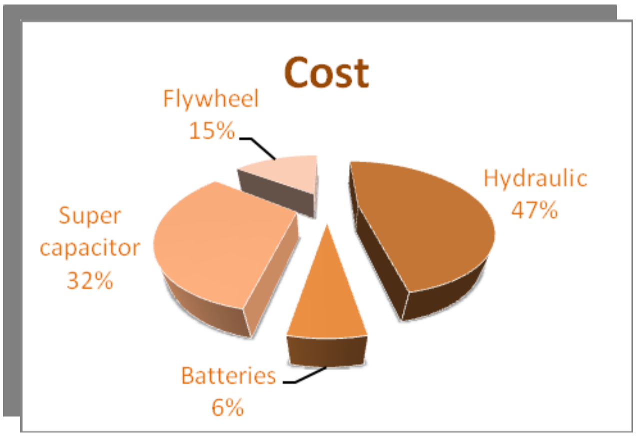

Fig. 6 Cost comparison of different KERS

Cost is the main drawback of every Hybrid vehicle. Causes of high cost are the materials used in making these vehicles and their storage technologies. Figure 6 shows that flywheel system is the cheapest after batteries with 15% and 6%. However, flywheels are currently use because of the efficiency they give in this low cost. Batteries cannot store enough energy and hence charge and discharge quickly. Hydrauic systems are the most expensive of them all followed by super-capacitorswith 47% and 32% respectively.

V. Conclusion

KERS is an effective type of regenerative braking which can fulfill the main purpose of hybrid vehicles i.e., storing and re-using energy lost while braking. The various types of KERS show different ways of storing and converting energy from one form to another. As per the analysis, flywheels have proven to be the best type of KERS so far in terms of voltage stability, temperature range and efficiency. If not for the large size and high cost, super capacitors have a high chance of replacing the mechanical storage device. This paper is a brief overview of the alternate type of KERS. More in depth analysis can be done on their functions. Studies are being carried out by some of the referred authors regarding the same. Further studies can also be done to improve the quality of present in-use KERS and further research and development could help in getting even more kinds of energy recoverable systems.

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References

[1] Chibulka J., “Kinetic Energy Recovery system by means of Flywheel Energy storage device,” *Advanced Engineering,* vol. 3, issue 1, pp. 27-38, 2009.

[2] Chicurel R., Lara P., “Control of a Hybrid Propulsion System,” *Instrumentation and Development*, vol.3, issue 6, pp. 3-7, 2009.

[3] M. Jayalakshmi, K Balasubramanium, “Simple Capacitors to Super Capacitors- An Overview,” *Int. J. Electrochem. Sci.,* vol. 3, pp. 1196-1217, 2008.

[4] Ricardo Chicurel, “A Compromise Solution for Energy Recovery in Vehicle Braking,” *Energy*, vol.24, pp. 1029-1034, 2009.

[5] Barr A., Veshagh A., “Fuel Economy and Performance Comparison of Alternative Mechanical Hybrid Powertrain Configuration,” *SAE 2008 World congress,* Detroit, USA, 2008.

[6] Brockbank C., Cross D., “mechanical Hybrid System Comprising a Flywheel and CVT for Motorsport & Mainstream Automotive Applications,” *SAE 2009 World Congress*, Detroit, MI, USA, 2009.

[7] Brockbank C., Chris Greenwood, “Fuel Economy Based Mechanical Hybrid for City Bus and commercial Vehicle Applications,” *SAE International Journal of Commercial Vehicles,* vol. 2, issue 2, pp. 115-122, 2010.

[8] Brutt D., “Fuel Economy Benefits of a High Torque Infinitely Variable Transmission for Commercial Vehicles,” *SAE 2007 Commercial Vehicle Engineering Congress,* Rosemont, IL, USA, 2007.

[9] Lee A., Newall J., “Durability of a Compact Dual-Cavity Full-Toroidal IVT Variator,” *SAE 2004 World Congress,* Detroit, USA, 2004.

[10] Newall J., Nicolson D., Lee A., Evans S., "Development and Assessment of Traction Fluids for Use in Toroidal IVT Transmissions,” *SAE 2002 World Congress,* Detroit, Michigan, USA, 2002.

[11] Medlicott P.A.C., “Development of A Light Weight Low Cost Flywheel Energy Storage System For A Regenerative Braking Application,*” The British Petroleum Company Plc. 20th Inter Society Energy Conversion Engineering Conference (IECEC),* Miami Beach, Florida, 1985.

[12] Flynn M. M., Zierer J. J., Thompson R. C., “Performance testing of a Vehicular Flywheel Energy System,” *Advanced Hybrid Vehicle Powertrains 2005*, SAE 2005 World Congress, Detroit, USA, 2005.

[13] Ayad M-Y, Pierfederici S., Raël S., Davat B., “Voltage Regulated Hybrid DC Power Source using Supercapcitors as Energy Storage Device,” *Energy Covers Manage*, 2007.

[14] Ayad M-Y, Becherif M., Henni A., Aboubout, Wack M., Lagroche S., “Passivity –Based Control Applied to DC Hybrid Power Source using Fuel Cell and Supercapacitors,” *Energy Covers Manage*, 2010.

[15] Payman A., Pierfederici S, Meibody-Tabar F., “Energy control of supercapacitor/fuel cell hybrid power source,” *Energy Convers Manage,* 2008.

[16] Uzunoglu M., Alam MS., “Dynamic modeling, design and simulation of a PEM fuel cell/ultra-capacitor hybrid system for vehicular applications,” *Energy Convers Manage,* 2007.

[17] Adib E., Farzanehfard H., “Soft switching bidirectional DC–DC converter for ultracapacitor–batteries interface,” *Energy Convers Manage,* 2009.

[18] Farzanehfard H., Beyragh D.S., Adib E., “A bidirectional soft switched ultracapacitor interface circuit for hybrid electric vehicles,” *Energy Convers Manage,* 2008.

[19] Rufer A., Hotellier D., Barrade P., “A supercapacitor-based energy storage substation for voltage compensation in weak transportation networks,” *IEEE Trans Power Del,* 2004.

[20] Chau K.T., Wong Y.S., Chan C.C., “An overview of energy sources for electric vehicles,” *Energy Convers Manage,* 1999.

[21] Sharma P., Bhatti T.S., “A review on electrochemical double-layer capacitors,” *Energy Convers Manage,* 2010.

[22] L. Guzzella, A. Sciarretta,”Vehicle Propulsion Systems: Introduction to Modeling and Optimization,” Springer, 2007.

[23] X. Zhang, C. Mi, “Vehicle Power Management: Modeling, Control and Optimization,” Springer, 2011.

[24] H. Shimoyama, S. Ikeo, E. Koyabu, K. Ichiryu, S. Lee, “Study on hybrid vehicle using constant pressure hydraulic system with flywheel for energy storage,” *SAE 2004-01-3064,* 2004.

[25] R. Johri, Z. Filipi, “Low-cost pathway to ultra efficiency car: series hydraulic hybrid system with optimized supervisory control,” *SAE 2009-24-0065,* 2009.

[26] P. Matheson, J. Stecki, “Modeling and simulation of a fuzzy logic controller for a hydraulic hybrid powertrain for use in heavy commercial vehicles,” *SA, 2003-01-3275,* 2003.

[27] Y.J. Kim, Z. Filipi, “Simulation study of a series hydraulic hybrid propulsion system for a light truck,” *SAE 2007-01-4151,* 2007.

[28] T. Lin, Q. Wang, B. Hu, W. Gong, “Research on the energy regeneration systems for hybrid hydraulic excavators,” *Automation in Construction,* vol. 19, pp.1016–1026, 2010.

[29] S. Cetinkunt, U. Pinsopon, C. Chen, A. Egelja, S. Anwar, "Positive flow control of closed-center electrohydraulic implement-by-wire systems for mobile equipment applications," Mechatronics, vol. 14, pp. 403–420, 2004.
[30] X. Lin, S. Pan, D. Wang, "Dynamic simulation and optimal control strategy for a parallel hybrid hydraulic excavator," *Journal of Zhejiang University. ScienceA 9,* vol. 5 pp. 624–632, 2008.
[31] D. Wang, C. Guan, S. Pan, M. Zhang, X. Lin, "Performance analysis of hydraulic excavator powertrain hybridization," *Automation in Construction,* vol. 18, pp.249–257, 2009.
[32] Q. Xiao, Q. Wang, Y. Zhang, "Control strategies of power system in hybrid hydraulic excavator," *Automation in Construction,* vol. 17 (2008) 361–367.
[33] R. Kordak, "Hydrostatic Transmission Drives with Secondary Control," Bosh Rexroth AG, 2003.
[34] Karden E, Ploumen S, Fricke B, Miller T, Snyder K., "Energy storage devices for future hybrid electric vehicles," *Journal of Power Sources,* pp.2-11, 2007.
[35] Kim YJ, "Integrated modeling and hardware-in-the-loop study for systematic evaluation of hydraulic hybrid propulsion options," *Doctor of Philosophy in the University of Michigan,* pp. 1-16, 2008.
[36] Stienecker AW, Stuart T, Ashtiani C., "An ultracapacitor circuit for reducing sulfation in lead acid batteries for mild hybrid electric vehicles," *Journal of Power Sources,* vol. 156, 2006.
[37] Paladini V., Donateo T., Arturo de Risi A.D., Laforgia D., "Super-capacitors fuel-cell hybrid electric vehicle optimization and control strategy development," *Energy Conversion and Management,* 2007.
[38] Ricardo C., "A compromise solution for energy recovery in vehicle braking," *Energy* 1999.
[39] Uzunoglu M, Onar OC, Alam MS., "Modeling, control and simulation of a PV/FC/UC based hybrid power generation system for stand-alone applications," *Renewable Energy,* 2009.
[40] Rodatz P, Paganelli G, Sciarretta A, Guzzella L., "Optimal power management of an experimental fuel cell/supercapacitor-powered hybrid vehicle," *Control Engineering Practice,* 2005.
[41] Thounthong P., Rael S., Davat B., "Control strategy of fuel cell/supercapacitors hybrid power sources for electric vehicle," *Journal of Power Sources*, vol. 158, 2006.
[42] Bozic A., "Introducing hydraulic-electric synergy into hybrid transmission using the free-piston engine technology," *SAE Paper 2007-01-4112,* 2007.
[43] S. Hui, Y. Lifu, Jing J., "Hydraulic/electric synergy system (HESS) design for heavy hybrid vehicles," *Energy, vol. 35,* 2010.
[44] Marin S. Halper, James C. Ellenbogen, "Supercapacitors: A Brief Overview," *MP 05W0000272*, 2006.