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Energy Management & Control Performance Analysis of Hybrid Electric Vehicle

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Abstract: The environmental aspect like oil depletion, global heating and CO2 gas emissions have become a concern and have propelled the development of an efficient and extendable energy management system (EMS) using fuel cell and battery sources for Hybrid Electric Vehicles. In this paper, a poser of a hybrid electric vehicle with energy management system with multiple source of energy is developed and analyzing the performance of HEV on Matlab. The multiple sources of energy, such as a battery and fuel cell (FC), EMS and power controller are designed and modelled using MATLAB. The developed control strategies continuously support the EMS of the multiple sources of energy for a vehicle under normal load conditions. The performance of the proposed system is analyzed in terms of vehicle speed and Load power. These study results suggest that the proposed control technique provides an efficient and feasible EMS for light electric vehicles.

Keywords: Energy Management System, Hybrid Electric Vehicle, Fuel Cell, Lithium Ion Battery.

I. INTRODUCTION

Around 90% of today's automobiles run on petroleum based product, which are estimated to be depleted by 2050. Moreover, current automobiles utilize only 27% of the energy released from petroleum and rest is wasted into the atmosphere. Despite recent efforts to improve fuel efficiency and reduce toxic emissions in cars, emissions have continued to increase steadily in the past two decades. For preservation of gasoline for future and increasing the efficiency of vehicle an electric vehicle can be a major breakthrough. An electric vehicle is pollution free and is efficient at low speed conditions mainly in high traffic areas. But battery charging is time consuming. Moreover, it cannot provide high power required by drives during high speed conditions or in slopes of hilly areas.
Therefore the combination of fuel cell and lithium ion battery is one of the best options for gaining high performance in electric vehicle. Gasoline engine proves its efficiency at higher speeds in high ways and waste a lot of energy in urban areas. A hybrid electric vehicle solves these problems by combining the fuel cell and lithium ion battery and uses both the power sources at their efficient conditions. The objective of this project aims at better utilization of fuel energy and reduces dependence on non-renewable resources using latest technology. The implementation involves development of HEV that uses battery as well as fuel cell power for propulsion of vehicle.

II. FUEL CELL

A fuel cell is a device that uses hydrogen as a fuel to produce electrons, protons, heat and water. Fuel cell technology is based upon the simple combustion reaction given in Eq. (2.1):

$$2H2 + O2 \leftrightarrow 2H2O \qquad (2.1)$$

The electrons can be harnessed to provide electricity in a consumable form through a simple circuit with a load. Problems arise when simple fuel cells are constructed. Simple fuel cells have a very small area of contact between the electrolyte, the electrode, and the gas fuel. Simple fuel cells also have high resistance through the electrolyte as a result of the distance between the electrodes. Therefore, as a result of these problems, fuel cells have been designed to avoid them. A design solution includes manufacturing a flat plate for the electrodes with an electrolyte of very small thickness between the two electrodes. A very porous electrode with a spherical microstructure is optimal so that penetration by the electrolyte and gas can occur. This design gives the maximum area of contact between the electrodes, electrolyte and gas thus increasing the efficiency and current of the fuel cell.

A fuel cell does not require recharging the same as a battery. In theory a fuel cell will produce electricity as long as fuel is constantly supplied. The basic design of a fuel cell involves two electrodes on either side of an electrolyte. Hydrogen and oxygen pass over each of the electrodes and through means of a chemical reaction, electricity, heat and water are produced. Hydrogen fuel is supplied to the anode (negative terminal) of the fuel cell while oxygen is supplied to the cathode (positive terminal) of the fuel cell. Through a chemical reaction, the hydrogen is split into an electron and a proton. Each takes a different path to the cathode. The electrons are capable of taking a path other than through the electrolyte, which, when harnessed correctly can produce electricity for a given load. The proton passes through the electrolyte and both are reunited at the cathode. The electron, proton, and oxygen combine to form the harmless by product of water. This process is shown in Fig. 2.1. The hydrogen fuel can be supplied from a variety of substances if a fuel reformer is added to the fuel cell system. Therefore, hydrogen can be obtained from hydro carbon fuel such as natural gas or methanol. The fuel cell's means for producing electricity is through a chemical reaction, therefore there are

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significantly cleaner emissions than from a fuel combustion process.

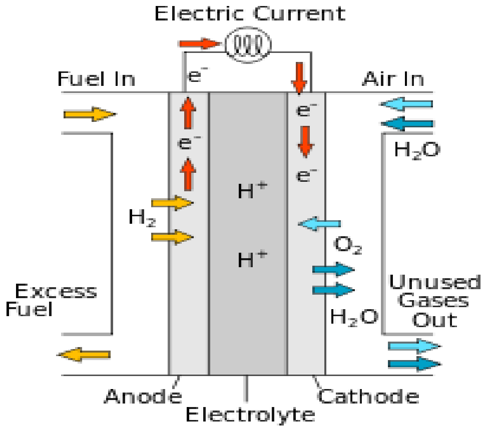

Figure 2.1: Basic Fuel Cell Operation

III. LITHIUM ION BATTERY

A lithium-ion battery is a rechargeable battery in which lithium ions move between the anode and cathode, creating electricity flow useful for electronic applications. In the discharge cycle, lithium in the anode (carbon material) is ionized and emitted to the electrolyte. Lithium ions move through a porous plastic separator and insert into atomic-sized holes in the cathode (lithium metal oxide). At the same time, electrons are released from the anode. This becomes electric current travelling to an outside electric circuit (see Figure 3). When charging, lithium ions go from the cathode to the anode through the separator. Since this is a reversible chemical reaction, the battery can be recharged (Yoshino, 2008).

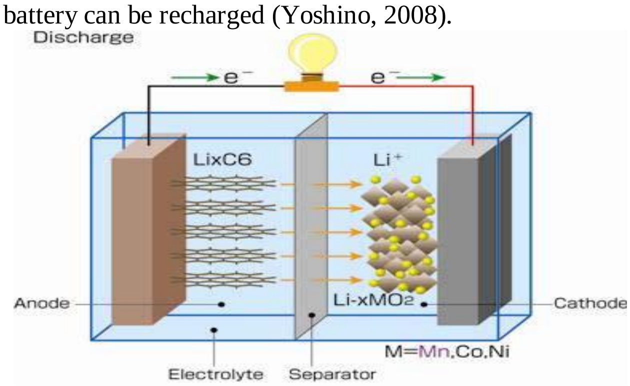

Fig 3. Discharging mechanism of a lithium-ion battery
Source: (Automotive Energy Supply Corporation, 2007)

A lithium-ion battery cell contains four main components: cathode, anode, electrolyte and separator.

Table 2 shows the main components' functions and material compositions. Lithium ion battery cells are sold in "battery packs," which include battery management systems. Lithium-ion batteries are the most suitable existing technology for electric vehicles because they can output high energy and power per unit of battery mass, allowing them to be lighter and smaller than other rechargeable batteries (see Figure 4). These features also explain why lithium ion batteries are already widely used for consumer electronics such as cell phones, laptop computers, digital cameras/video cameras, and portable audio/game players. Other advantages of lithium-ion batteries compared to lead acid and nickel metal hydride batteries include high-energy efficiency, no memory effects,3 and a relatively long cycle life (see Table 1).

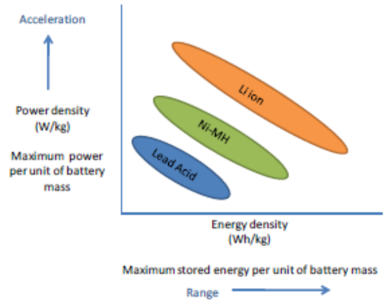

Figure-4. Power (acceleration) and energy (range) by battery type

Battery type	Lead acid	Ni-Cd	Ni-MH	Lithium-ion
Energy density[a] (Wh/Kg)	35	40-60	60	120
Power density (W/kg)	180	150	250-1000	1,800
Cycle life[c]	4,500	2,000	2,000	3,500
Cost ($/kWh)[d]	269	280	500-1,000	Consumer electronics: 300-800 Vehicles: 1,000-2,000
Battery characteristics	High reliability, low cost	Memory effect	Currently, best value and most popular battery for HEVs	Small size, light weight
Application	Car battery, forklift, golf cart, backup power	Replacement for flashlight battery	HEVs, replacement for flashlight battery	Consumer electronics

Table1. Technical performance by existing battery type

a: Chargeable electric energy per weight of battery pack
b: Proportion of dischargeable electric energy to charged energy
c: The number of charging/discharging cycles in battery's entire life
d: Calculated exchange rate approximate is Rs.5
e: Lithium-ion batteries for consumer electronics have lower costs than those for vehicle use because of high volume production and a mature market.
Source: (Deutsche Bank, 2009; METI, 2009a; Nishino, 2010; The Institute of Applied Energy, 2008; Wood bank Communications Ltd, 2005)

IV. ENERGY MANAGEMENT SYSTEM

The EMS controls all of the energy sources that have different tasks in delivering power to the load. The battery is the main energy source of the vehicle. Once the start button is triggered, system determines the battery capacity and the pedal acceleration. Then, based on the control algorithm, the EMS determines which energy sources should be activated. The battery also functions as a storage device that receives charges from the FC or through plug-in. The FC is the secondary energy source of the vehicle. It starts supplying energy to the load and, at the same time, recharges the battery when the battery capacity is below 50%. Since FC need few minutes for start-time to be full operation, amount of energy from the battery must be reserved. The battery capacity 50% is considered as enough until FC can overtake the battery. Besides, charge and discharge a battery far below 50% its capacity can reduce its life-cycle tremendously. If the battery reaches full capacity, the FC supply is cut off. Any excess energy from the FC is stored in the battery. The SC supports After the EMS has been triggered, it recharges and waits for the next request. energy sources when both the battery and FC still not adequate to support high power demands.

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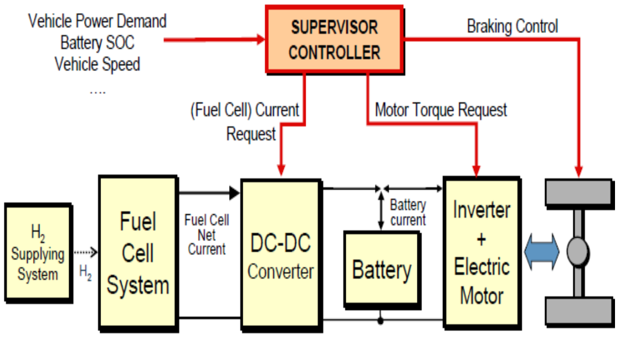

Fig.5 Control signal flow in HEV. The power split ratio between the battery and the fuel cell system is managed by the supervisor controller sending the fuel cell net current request to the DC-DC converter

V. Simulation & Result

The performance evaluations for the EMS of the hybrid electric vehicle are investigated in terms of the vehicle speed, power load and multiple source loading conditions. The performance of the developed system is analysed in the proposed model.

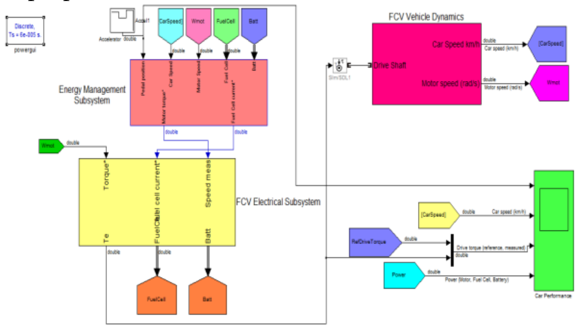

Fig 6: Hybrid Electric Vehicle with Energy Management system

The **Energy Management Subsystem** (EMS) determines the reference signals for the electric motor drives, the fuel cell system and the DC/DC converter in order to distribute accurately the power from the two electrical sources. These signals are calculated using mainly the position of the accelerator, which is between -100% and 100%, and the measured FCV speed. The Battery management system maintains the State-Of-Charge (SOC) between 40 and 80%. Also, it prevents against voltage collapse by controlling the power required from the battery.

In one complete cycle, the model of Hybrid Electric Vehicle shows different operating modes: accelerating, cruising, recharging the battery while accelerating and regenerative braking.

Run the model. In accelerator mode it will run approximately 55-60 sec. we can see that the HEV speed starts from 0 km/h to about 87 km/h at 10 s, and finally decreases to 76 km/h at 17 s. This result is obtained by maintaining the accelerator pedal constant to 75% for the first 4 s, and to 25% for the next 4 s when the pedal is released, then to 85% when the pedal is pushed again for 4 s and finally sets to -75% (braking) until the end of the simulation.

At t = 0 s, the HEV is stopped and the driver pushes the accelerator pedal to 75%. Now, the battery provides the motor power till the fuel cell starts.

- At t = 0.7 s, the fuel cell begins to provide power but is not able to reach the reference power due to its large time constant. That's why the battery continues to provide the electrical power to the motor.
- At t = 4 s, the accelerator pedal is released to 25%. The fuel cell cannot decrease its power instantaneously; therefore the battery absorbs the fuel cell power in order to maintain the required torque.
- At t = 6 s, the fuel cell power is equal to the reference power. The battery is no more needed.
- At t = 8 s, the accelerator pedal is pushed to 85%. The battery helps the fuel cell by providing an extra power of 25 kW.
- At t = 8.05 s, the total power (fuel cell and battery) cannot reach the required power due to the fuel cell response time. Hence the measured drive torque is not equal to the reference.
- At t = 8.45 s, the measured torque reaches the reference. The fuel cell power increases so the battery power is progressively reduced to 6 kW.
- At t = 10.9 s, the battery SOC becomes lower than 40% (it was initialized to 40.32 % at the beginning of the simulation) therefore the battery needs to be recharged. The fuel cell shares its power between the battery and the motor. we can observe in scope that the battery power becomes negative. It means that the battery receives some power from the fuel cell and recharges while the HEV is accelerating. At this moment, The required torque cannot be met anymore.
- At t = 12 s, the accelerator pedal is set to -75% (regenerative braking is simulated). The motor acts as a generator driven by the vehicle's wheels. The kinetic energy of the FCV is transformed in electrical energy which is stored in the battery. For this pedal position, the required torque of -140 Nm cannot be reached because the battery can only absorb 25 kW of energy. The fuel cell power decreases according to it response time.

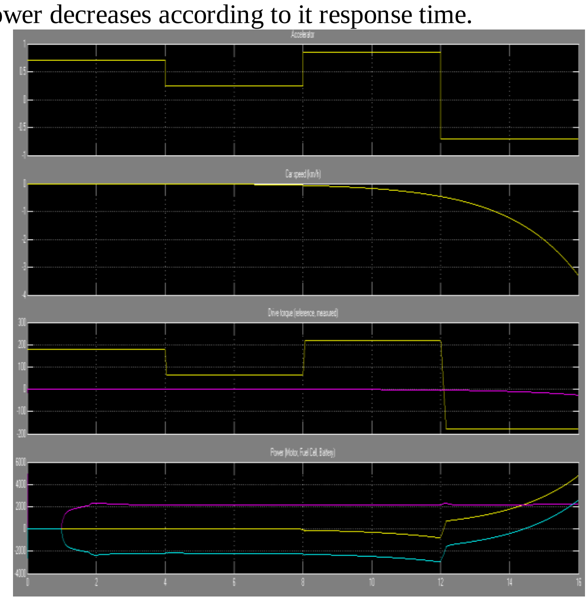

Figure 5.1: Car performance of system

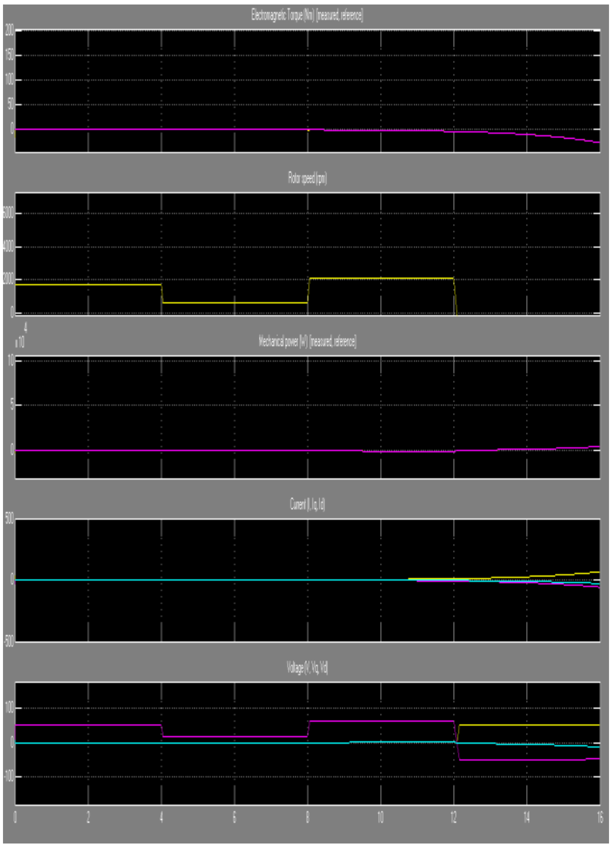

Figure 5.2 : Performance of PMSM Drive

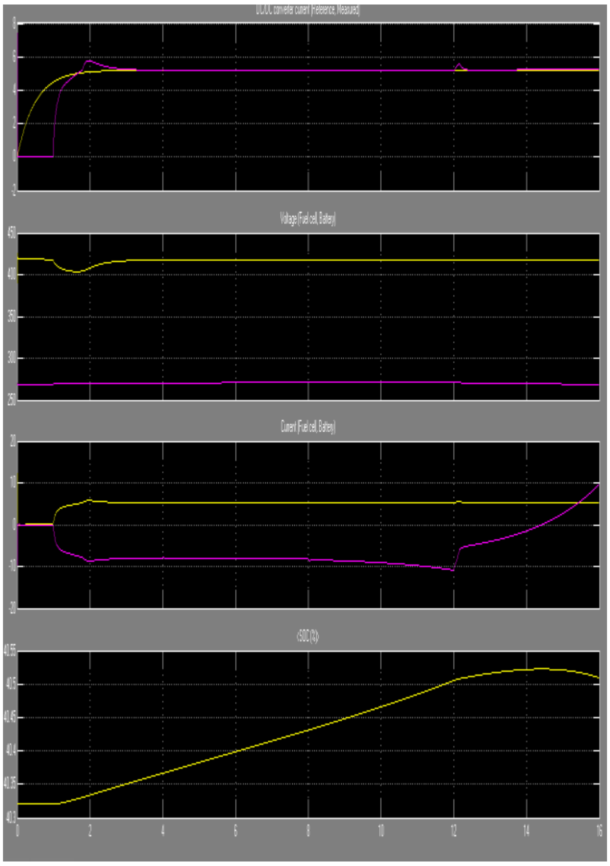

Fig 5.3: Performance of fuel cell, battery and battery SOC

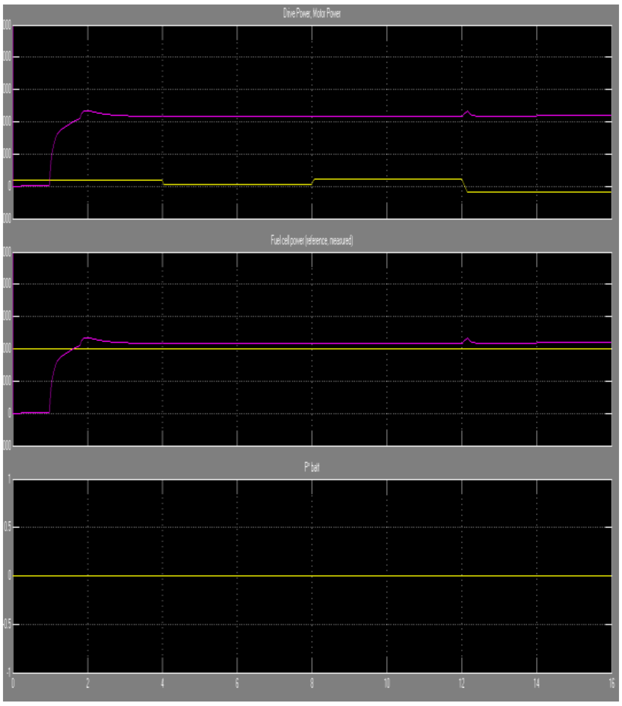

Figure 5.4: Performance of Power Management System

VI. CONCLUSION

In this paper, an overview of different energy source models and a new control state-based EMS is introduced for light electric vehicles for next-generation transportation. HEV is a vehicle that uses two sources of power- Fuel cell and battery. This source has good potential for providing powerful power to the HEV. Using the energy management system in HEV the efficiency becomes improved. In this model the logic sequences of the vehicle EMS under the operational control strategy directly influences the energy harvesting of the hybrid electric vehicle from the renewable sources. According the performance of HEV, results show that the control strategies, vehicle speed and load power are close to the CI vehicle under normal condition. Now, various kinds of energy management have been designed with positive feedback. Thus, there is no doubt that these renewable energies will be our next generation of energy sources in the near future.

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BIOGRAPHIES

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Dr. Jyoti Shrivastava has done her graduation in Electrical Engineering and her post graduation in Design of Heavy Electrical Equipments. At present she is serving as an Senior Assistant Professor in Electrical Engineering department at college of Engineering and Technology, SHIATS, Allahabad, India. She has several international and National papers to her credit. Her field of interest and research are Power system control and operation, power quality improvement and condition monitoring of heavy electrical equipments. Her research aims to increase Transmission & Distribution system capacity and enhancing system reliability.