Energy Management Schemes for fuel cell Hybrid Electric Vehicles.

Ms. Yogita B More  
PG Student,  
Electrical Engineering Dept.  
SNDCOERc Yeola.

Dr. P.C. Tapre  
HOD  
Electrical Engineering Dept.  
SNDCOERc Yeola

ABSTRACT

This paper presents a comparative study between rule based and frequency separation energy management strategies within hybrid electric vehicle, using a Fuel cell (FC) as an energy source, and batteries as power source. FC supplies the main energy while battery supplies power peaks for fast acceleration and captures the braking regenerated energy. In this paper, we have shown the advantages and the limits of each one. This work is validated by simulation and experimental results, which are carried out using dynamic model of electric vehicle and taking into consideration the external environment effects. 

Keywords  
FC, battery, Boost converter, Buck-boost converter, Frequency separation energy management.  

1. INTRODUCTION

The energy management strategy is a very important element in fuel-cell vehicle (FCVs) [1], and its main function is to share the energy flow between sources on board the vehicle [2]. The problem of energy management is to find the best distribution of power between the different energy sources [3]. Several performance criteria involved in choosing this distribution, such as the sources lifetime, driving comfort, autonomy etc. [4], [5]. Many energy management techniques (EMS) are developed in the literature for hybrid power sources based on fuel cells. Among these techniques is the rule-based strategy, which is simple to implement; therefore, this strategy depends on reasoning of the designer. [6]. The strategy based on frequency separation aim to attributes low frequencies to the fuel cell, and the auxiliary sources give high frequency power to the load [7], [8]. Our project deals with a comparative study between rule based and the strategy based on frequency decoupling within hybrid fuel-cell electric vehicle, in order to benefit from the advantages of each one. The world faces a serious challenge in energy demand and supply. People around the world consume approximately 85 million barrels of oil every day but there are only 1300 billion barrels of proven reserves of oil. At the current rate of consumption, the world will run out of oil in 2050. New discoveries of oil reserves are at a slower pace than the increase in demand. Among the oil consumed around the world, 60% is used for transportation [1]. Gasoline and diesel fuel-powered vehicles are among the major contributors to CO2 emissions. In addition, there are other emissions from conventional fossil fuel-powered vehicles, including carbon monoxide (CO) and nitrogen oxides (NO and NO2, or NOx) from burning gasoline; hydrocarbons or volatile organic compounds (VOCs) from evaporated, unburned fuel; and sulfur oxide and particulate matter (soot) from burning diesel fuel. These emissions cause air pollution and ultimately affect human and animal health [1]. It is why the society needs sustainability, but the current model is far from it. Cutting fossil fuel usage and reducing carbon emissions are part of the collective effort to retain human uses of natural resources within sustainable limits. Therefore, future personal transportation should provide enhanced freedom, sustainable mobility, and sustainable economic growth and prosperity for society. In order to achieve these, vehicles driven by electricity from clean, secure, and smart energy are essential, but electrically driven vehicles have many advantages and challenges. Hybrid vehicles and fuel cells can be one of the solutions. Fuel cell vehicles (FCVs) use FCs to generate electricity from hydrogen. The electricity is either used to drive the vehicle or stored in an energy storage device, such as battery pack. Since FCs generates electricity from chemical reaction, they do not burn fuel and therefore do not produce pollutants. The byproduct of a hydrogen FC is water and heat. FCVs provide quiet operation and more comfort with zero emissions. These vehicles are efficient, reliable, optimum, and long lasting at reasonable cost. They have greater efficiency compared to heat engines; FCVs could be a long-term solution [2]. To meet the never ending fuel demand of the vehicle, Hybrid Vehicle was introduced in the research. Generally a hybrid vehicle is the combination of an internal combustion engine (ICE) and electrical drive system. The performance of the vehicle is largely dependent on the accuracy and efficiency of the electrical system of the vehicle powertrain. This paper analyzed an electrical system for the powertrain of Hybrid Electric vehicle which is powered by Fuel cell, Battery and PV panel. Including this the research also compared the performance of energy storage system with the reference which is frequently used in the electrical system of the HEV. According to the center of solar energy and hydrogen research a total number of 550,000 new hybrid electric vehicle registered till 2015 [1]. Based on the use of energy storage system electric vehicle can be classified into battery electric vehicle, hybrid electric vehicle and plug-in hybrid electric vehicle [2]. The key factor behind the evolution of Hybrid Electric Vehicle is the improved performance of power electronics and performance oriented motor drives. The performance of the powertrain of HEV is solely dependent on the performance of motor drives. The demand of hybrid electric vehicle are increasing day by day due to immense improvement in the performance of various power electronics devices like converter, switches and motor drives [3]. Besides, the development in the hardware of the hybrid electric vehicle, a silent revolution is also happened in the field of software of HEV. A hybrid electric vehicle is generally consists of an ICE.
and motor for propulsion. Vehicle manufacturer are emphasizing on hybrid electric vehicle because safety of environment is a global manifesto. To keep the environment safe hydrogen was introduced as a fuel source of the vehicle. Fuel cell technology specifically proton exchange membrane fuel cell (PEMC) used vastly to utilize hydrogen as major fuel source of the vehicle. As an environmentally safe and efficient fuel hydrogen is the vital choice for the manufacturer in case electric vehicle. The main advantage of hybrid electric vehicle beside the improved fuel economy is the reduction of carbon-di-oxide emission [4]-[5]. The carbon dioxide emission rate on May 2016 was near 407.70 ppm and it is simultaneously increasing [6]. Hybrid electric vehicle uses many state of the art environment friendly technologies like regenerative braking system, fuel cell etc. which will greatly reduce the emission of harmful elements whose are responsible for environment pollution. Along with this green technologies use of efficient power electronics and lighting system will greatly improve the overall performance of hybrid electric vehicles.

1.1 Energy Management System
Tendency toward renewable power systems, especially PV and Wind plants, have been increased both in rural and ur-ban areas in recent years [1]. This tendency is mainly due to the limited natural resources, green gas emissions, increased energy consumption, and economic aspects [2]. In addition to mitigating environmental crisis, standalone hybrid renew-able systems can be an alternative to electrification of re-mote regions which large power grids cannot meet their energy needs. Due to unpredictable and random sun insolation and wind speed which leads to fluctuant renewable energy generation, any mismatch between the energy demand and the energy production can lead to instability, power quality degradation, failure, etc. [3]. Thus, interconnecting a sup-port system and storage units is a necessary step to regulate the electricity generation and provide a reliable path for power generation and consumption [4]. The batteries and hydrogen based storage technologies provide a reasonable solution for this problem [5]. Additionally, super capacitors, with peak demand shaving, reduce the energy production cost, overcome high renewable energy/load power fluctuations, and prolong the energy sources and the battery banks life span [6]. The support system can be conventional diesel generators or fuel-cells. Of course, due to lower maintenance cost and near zero pollutant emissions, fuel-cells are more preferable than diesel generators [7]. The proper operation of hybrid renewable systems depends on an elaborate design of an energy management unit [8-10] which meets the load power requirements, controls the batteries/super capacitors SOC, optimizes the fuel consumption, minimizes the pollutant emissions, and etc.

An isolated hybrid renew-able power system, which is also known as microgrid, comprising PV and wind renewable energy sources along with various energy storage technologies, is chosen for study, as shown in Fig.1. Analysis of microgrids via the centralized energy management strategies, such as dynamic programming [9], model predictive control [10], sequential quadratic programming [11] and mixed integer programming [12] normally require high computations and have been dis-cussed in the literature. A comparative study of different state machine power management strategies for a renewable energy system has been discussed in [13], in which in addition to comparison of the approaches, the effect of the minimum battery state of charge and the fuel-cell output power on the hydrogen inventory has been discussed for a four month time interval. The state machine is an energy control strategy with short response time, but is sensitive to the measurement accuracy and moreover requires an exact mathematical model of the system. Hence uncertainties in hybrid renewable systems such as unpredictable and fluctuated PV/Wind power generation, the variations in the load power, mathematical model inaccuracies, and complexity of the hybrid system led the authors toward the fuzzy logic based energy management systems [14]. Focusing on the optimization of the battery lifetime and the utilization cost, the authors in [14] presented a fuzzy logic based supervisory control for a PV/WT hybrid system. Given the challenges such as the fuzzy logic control dependency on prior knowledge and past experience of the designer and time consuming tuning process of the membership function's parameters by trial and error and difficulty of selecting the most appropriate rule set, the ANFIS based energy management strategy is attracting growing attention. It is well known that the ANFIS-based energy management strategy in addition to serving the capabilities of the fuzzy logic (control strategy) along with learning abilities of artificial neural networks, improves the reliability of the hybrid renewable system, because of employing the Sugeno type fuzzy inter-face system [15-19]. Thus, the authors in [15-19] employed the ANFIS-based energy management system for a grid connected hybrid renewable system. Moreover, short term analysis of hybrid renewable systems based on the state ma-chine control [16] and the fuzzy logic control [17] has been presented by the authors in the past. The authors in [18] designed the fuzzy rules based on the battery SOC, to increase the battery lifetime. This paper presents a comparative investigation of the conventional state machine control, the rule based fuzzy logic control, the ANFIS based control strategy, and the equivalent consumption minimization strategy (ECMS) for the standalone hybrid renewable system shown in Fig.

In this Project, the state machine control is designed based on the battery bank SOC and the load power shortage that is not supplied with the PV and wind energy sources. Besides the demanded energy supply, the state machine control aims to protect the battery bank from deep discharge and overcharge. The ANFIS based energy control is based on the input/output data process of the hybrid renewable system. The data requirements of the ANFIS-based control can be satisfied via the state machine control strategy [15]. On the other hand, the input/ output data generated through the state machine control, gives the opportunity of mixing the ANFIS-based control strategy capabilities with the design approach of the state machine control. Hence, in addition to extending the battery lifetime, more efficiency and robustness is achieved with the ANFIS-based control capabilities. The ECMS minimizes the fuel consumption of the fuel-cell and equivalent hydrogen consumption of the battery bank via a cost function which employs an equivalent factor to calculate the battery bank equivalent hydrogen consumption. It uses a local optimization algorithm to allocate the load power (or a part of the load power) to the fuel-cell and the energy storage banks in a way that total fuel consumption is minimized [19]. Similar to ECMS, the EEMS employs a local optimization algorithm. In this strategy, maximizing the instantaneous energy of the battery bank and the super capacitors, leads to economized fuel consumption.
1.2 Introduction to Fuel Cell Model

Fuel cell is an integral part of the proposed hybrid electric vehicle power system. The use of fuel cell was initiated by NASA as supporting power source to meet the power demand of their space shuttle. Overall performance of the vehicle specifically the fuel economy of the vehicle depends on the vehicle energy management system where the power distribution between the fuel cell and battery is done. Fuel Cells are electrochemical energy converters. They can be seen as black boxes turning chemical energy contained in a fuel directly into electrical energy while generating heat and water as byproducts. The mechanism involved in this conversion is the same as the one for batteries. The primary difference is that the battery contains the reactants that generate electricity whereas those reactants need to be supplied externally to the fuel cell i.e. a battery needs to be thrown away or recharged once those reactants are depleted while the fuel cell can be refueled by refilling the tank with hydrogen. In this respect they are comparable to internal combustion engines which generate mechanical power with heat and exhaust gases as byproducts.

2. ENERGY MANAGEMENT SCHEMES

Calculating the global number of vehicles on the planet is an inexact science, but according to some approximate statistics, it could double from 1.2 billion in 2014 to 2.5 billion by 2050. In such a situation, reducing or even keeping pollutant emissions at today’s level needs special efforts from car manufacturers. These environmental issues together with the necessity to preserve petroleum resources have conducted scientists to propose hydrogen as a promoting alternative fuel [1]. From hydrogen, a Fuel Cell (FC) can itself generate electricity via an electrochemical reaction with the oxygen molecules and releases only pure water [2].

Clean and silent at any size, the Proton Exchange Membrane Fuel Cell (PEMFC) has significantly affected electric propulsion from scooter to aircraft [3–7] and especially Electric Vehicles (EV) [8–12]. In fact, the Fuel Cell Electric Vehicle (FCEV) is already being marketed in several marks and designs such as Mercedes-Benz F-Cell, Hyundai Tucson Fuel Cell Electric Vehicle (FCEV), Toyota Mirai, Honda Clarity, etc. [13].

fuel cell-based source is not always sufficient to meet vehicle demands, this is mainly due to its slow dynamic of operation and starting [14]. Hybridization of the FC with one or various auxiliary sources is in fact crucial to assure great driving range and speed for the EV.

A hybrid Electric Storage System (ESS) consisting of a Battery (BAT) and a pack of Ultra capacitors (UC) is used in this paper. It offers the advantages to assist the fuel cell and to recover regenerative energy at braking [15–17]. This hybrid ESS could be replaced by the new technology of lithium-ion capacitors in the next few years [18,19]. The FC represents the main source of the system. It supplies the majority of the demand whereas battery provides the complement of the required energy during FC start up and high load demand (acceleration, high road slope). For the ultra-capacitors, known to have a high dynamic of operation, they are requested to provide pulse load requirements in order to ensure the power balance between the demand and the generation and to maintain the system output voltage constant during operation. Although FC/BAT/UC hybrid system exhibits high efficiency and good energetic capability [20], performance of FCEVs depends essentially on how to manage the energy between the various components of the traction string. Otherwise, a Strategy of Energy Management (EMS) is quite necessary to optimally split the power between the sources and the load.

The main objectives of such a strategy are to minimize the fuel-hydrogen-consumption during missions, to secure the sources from critical operating conditions and to ensure the higher reliability and durability for the hybrid system. A variety of EMSs has been employed in automotive research from which we cite fuzzy logic control proposed in, neural network technique treated in, dynamic programming given in , predictive control strategy illustrated in, adaptive energy management based on a fuzzy logic system and optimal sizing developed in and the load-following approach proposed in to adapt the FC net power to load demand. More approaches and details are provided in . In fuzzy logic approach, fuzzy rules usually stem from engineering intuition and unfortunately cannot be optimized for each mission profile. Furthermore, neural network and dynamic programming techniques require advanced information on the entire load profile and an extensive computational effort, while a compromise between accuracy and simplicity should be considered in on-board energy management applications.

2.1 Rules-Based Energy Management Strategy

The rules-based energy management is considered as six degrees of freedom strategy, based on logical reasoning, which is translated to a simple set of rules, and aims to minimize as much as possible the fuel consumption, under constraint to maintain the state of charge of the storage element constant. Generally, the idea of choosing the storage element state of charge limits, is to maintain it within an acceptable range, in order to ensure the traction of the vehicle on its own, and to absorb the braking energy. On the other hand, the limits on the fuel cell power offer an additional degree of freedom to optimize its operation. In this strategy, there are three possible operation modes of the vehicle, such as: the “traction” mode, the “off” mode, and the “braking” mode. On the other hand, the limits on the fuel cell power offer an additional degree of freedom to optimize its operation. In this strategy, there are three possible operation modes of the vehicle, such as: the “traction” mode, the “off” mode, and the “braking” mode.
Fig No 2 Rules-based energy management algorithm in "braking" mode

Yes

Yes

No

No

Pveh = Pbatt

Pveh = Pbatt

Pveh = Pbatt

Pveh = Pbatt

Fig No 3 Rules-based energy management algorithm in "traction" mode

Where: Pveh, Pbat, Pfc, Ps, Pbat-min, Pfc-min, Pbat-max, Pfc-max, E(Ps), Emax, Emin, Etare respectively the: vehicle power, battery power, FC power, storage element absorbed/supplied power, minimum charge/discharge battery power, minimum FC power, maximum charge/discharge battery power, maximum FC power, state of energy of the battery when absorbed Ps power, maximum battery energy, minimum battery energy, battery energy at t instant. We are chosen the NEDC cycle as a profile of the speed.

Table No 1 Vehicle Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbol</th>
<th>Value</th>
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<td>1400 kg</td>
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<tr>
<td>Frontal area</td>
<td>S</td>
<td>2 m²</td>
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<tr>
<td>Drag coefficient</td>
<td>Cd</td>
<td>0.335</td>
</tr>
<tr>
<td>Rolling friction</td>
<td>Fr</td>
<td>0.009</td>
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<tr>
<td>density of the air</td>
<td></td>
<td>12 kgm³</td>
</tr>
<tr>
<td>Gravity</td>
<td>G</td>
<td>98 ms⁻²</td>
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Table No 2 Sources and Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
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<td>Nominal motor power</td>
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<tr>
<td>DC bus voltage</td>
<td>400 V</td>
</tr>
<tr>
<td>Nominal FC power</td>
<td>40 kW</td>
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</table>
2.2 Frequency Separation Technique

The aim of the frequencies separation energy management technique [3], [15], [16] is to share the load power between the FC and batteries, in order to respects the dynamic of these sources and give batter life time to the FC. In this strategy high frequencies are given by batteries and low frequencies are given by the FC.

![Fig No 4 Principle of frequency separation energy management strategy](image)

3. RESULT ANALYSIS

3.1 Structure of the Hybrid Source

As shown in Fig.5, the studied system comprises a DC link supplied by a FC and a Non-reversible DC-DC boost converter which maintains the dc voltage Vdc to its reference value Vdc and battery storage device which is connected to the dc link through a current reversible DC to DC converter. The function of FC is to supply the mean power to the load, whereas the storage device is used as a power source: it supplies peak loads required during acceleration and braking [5].

![Fig No 5 Hybrid Sources Structure](image)

3.2 Fuel cell Hybrid Electric vehicle Configuration

A variety of hybrid EV configurations has been proposed in the literature. The selected topology is presented in Figure 6. The hybrid source consists of a PEMFC, a lithium ion (li-ion) battery and a pack of ultra-capacitors coupled in parallel in a dc link and can supply together or separately the inverter of the traction motor through DC-DC converters. This configuration offers more flexibility in the control of the dc bus voltage that should be maintained constant during operation.

![Fig No 6. Fuel cell hybrid electric vehicle configuration](image)

3.3 Simulink Model of Electrical Vehicles

![Fig No 7 Simulink model of Electrical vehicle](image)

![Fig No 8 Simulink model of vehicle dynamics](image)
CONCLUSION

In this paper, two energy management techniques within Fuel Cell Vehicles were studied and simulated. The first technique is based on the frequency separation of powers, and the second is based on rules. A comparative study between frequency separation strategy and rule-based strategy shows that they are complementary, where the first gives a good dynamic to the FC but does not respect its limits in power, while the second limits the FC power but does not give a good dynamic. It seems beneficial to combine the two strategies in order to benefit from the advantages of each one.

REFERENCES


International Conference on Green Energy (ICGE), Feb 2014, pp. 170-175;


