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FUZZY LOGIC BASED ENERGY MANAGEMENT SYSTEM FOR HYBRID ELECTRIC VEHICLE

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ABSTRACT

Hybrid electric vehicles have gained attention throughout the globe with its advantage of green technology and reduced greenhouse gases emission. Moreover, hybrid vehicles being powered by battery would be the best option of replacing current petrol or gas dependent vehicles. There are drawbacks though; battery has limited lifetime and is very costly. Hence, it is hybridized with other energy storage systems such as supercapacitor. This paper focuses on the energy management system for the energy storage system consisting battery and supercapacitor of a hybrid electric vehicle using fuzzy logic based controller. The energy management system, which manages energy feed between battery and supercapacitor, is then simulated in Matlab/Simulink to verify its reliability and validity of operation.

Keywords: Battery, Supercapacitor, Energy management, Fuzzy logic, Hybrid electric vehicle, Simulation.

Contribution/ Originality

The paper's primary contribution is finding an energy management that could distribute or split energy between two sources of which in this paper is using battery and supercapacitor. The energy management in this paper uses fuzzy logic control to split the energy between the two energy sources.

1. INTRODUCTION

The current trend in automotive manufacturing has taken a drastic turn with the initiative of considering other energy sources such as battery and even fuel cell or supercapacitor to drive vehicles. We can see this with the emergence of hybrid vehicles such as Toyota Prius and Honda Insight and manufactured as in mass production. Honda has even expanded the hybrid technology into their other models such as Honda Civic, Honda Accord and Honda CRZ. The trend has recently evolved with the technology transforming from gas-electric hybrid into fuel cell hybrid

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vehicles such as Toyota Mirai and Honda Clarity FCX. This is strongly related to the limitation of fossil fuel resources and environmental issues of the greenhouse gases emission [1].

The expectation of researchers and scientist in the hybrid electric vehicles (HEV) and fuel cell hybrid electric vehicles (FC HEV) is the independency to fossil fuel and possibility of it being a green technology. However, there are several concerns; technical and non-technical factors, of implementing these battery or hydrogen-powered automobiles. Amongst them would be the perception of society, durability, refueling infrastructure, safety and sustainability, cost, etc. Technical factors would be another part that has to be studied, investigated and tested by researchers and manufacturers before seeing these vehicles take over the highway. The technical considerations would be the well-to-wheels efficiency, of which requires the implementation of all components with the highest efficiency into the system [2].

Research on the efficiency of each component; battery, supercapacitor, motor, inverter, dc-dc converter, and energy management system, in the FC HEV is currently being done in a high volume. However, this study focuses on the energy management system for hybrid electric vehicle. The energy management system which embeds fuzzy logic manages the energy feed to be drawn from either one of the energy sources battery and supercapacitor. Energy storage systems; battery and supercapacitor, vehicle model, and energy management system is elaborated in the following chapters.

2. ENERGY STORAGE SYSTEM FOR HEV

Energy storage systems for hybrid electric vehicles are battery and supercapacitor. These two devices act as electrochemical storage but having different characteristics, complementing one another in a hybrid energy system. This is due to the fact that battery has high energy density but low power density which enables them to store a lot of energy but dissipating them slowly. On the other hand, supercapacitors have high power density but low energy density, making them unable to store high amount of energy but able to dissipate energy at fast rate. In a hybrid electric vehicle, with various operating conditions, speed, and required power, the combination of both battery and supercapacitor would allow the lifetime of the battery extended since the energy during transient or peak load power could be drawn from the supercapacitor [3].

2.1. Battery for HEV

Battery has been used for dc energy source and also as energy storage since it is an electrochemical device which can convert chemical into electrical energy. In hybrid electric vehicles, it is essential since a lot of energy is wasted during the vehicle is braking [4]. Installing a battery will enable the regenerative braking energy to be used rather than wasted in a normal internal combustion engine (ICE) driven vehicle. However, the installation of battery for a hybrid electric vehicle is not as easy as it seems despite the fact that there are several types in the market. The batteries commonly used in vehicular applications are based on certain considerations such as its capacity, energy density, efficiency and lifetime or life cycle [3].

Among batteries used for lightweight electric vehicle are lead-acid battery due to its cost but, its disposal is a major concern. Environmental friendly nickel-metal hydrides are being used in electric vehicles but requires complicated charging algorithm and has long charging time. Lithium-ion would be the most reasonably used battery in electric vehicles due to its high energy density, long life cycle and is light in weight. However, its high production cost is a major drawback to its superior characteristics. Other batteries such as nickel-zinc, nickel-iron, and nickel-cadmium are not favored in electric vehicles due to factors of short life cycle, high self-discharge rate, and high maintenance cost, respectively [2].

2.2. Super Capacitor for HEV

Supercapacitors (or also known as ultracapacitor) are energy storage systems structured somewhat similar like capacitors but with very high capacitance and long lifetime. The supercapacitors used in electric vehicles are electric double layer capacitor (ELDC), pseudo capacitor, and hybrid capacitor. However, the most common supercapacitor used in hybrid electric vehicles is electric double layer capacitors (EDLC) due to it having the highest power density (1-3 kW/kg). It has the lowest energy density though (5-7 Wh/kg) among all three supercapacitors [2].

3. VEHICLE AND POWERTRAIN MODELING

The energy management system is designed to manage between energy sources within certain conditions. These conditions have parameters which include the speed and required power from the vehicle; hence, the vehicle is modeled in Matlab/Simulink. It is known that the vehicle power is closely related to the speed of the vehicle. This speed of the vehicle can be represented by the driving cycle consisting of starting, accelerating (or hill climbing), braking, and cruising condition. The driving cycle is set at 810 seconds for a total of 12.195 miles (approximately 19.62 km) simulated travelling distance. The parameters of the vehicle used in Matlab/Simulink for the hybrid electric vehicle modeling and simulation are shown in Table 1.

Table-1. Parameters of the hybrid electric vehicle

Parameters	Value
Mass of the vehicle	990 kg
Mass (vehicle plus passengers)	1630 kg
Max speed	90 km/h
Aerodynamic coefficient	0.31
Efficiency of the powertrain	60%
Rolling friction coefficent	0.015

4. FUZZY LOGIC BASED ENERGY MANAGEMENT SYSTEM

There are quite a big number of researches implementing fuzzy logic in the energy management system [5]. It seems to be very appropriate since it determines the condition as in a state. The ability to determine the output based on a condition is what makes it flexible, making it close to human decision. It operates based on lingual 'if..then' rules [6] and considering uncertainties that usually incur when determining output, fuzzy logic is considered reasonable and logic. In this paper, fuzzy logic controller is used as the energy management system for the hybrid electric vehicle. In order to determine the conditions, the input and output variables have to be verified first. Implementation of fuzzy logic controller, the three major stages have to be determined prior to the design of the fuzzy logic. These three stages are (1) fuzzification, (2) inference, and (3) defuzzification. Fuzzification is the process of creating fuzzy sets, where the input and outputs are defined and the membership functions are formed. Inference is the stage where the set of rules are created according to the input and output variables. Some of the fuzzy rules used in this fuzzy logic controller are showed in Table 2. Defuzzification is the process of producing a single crisp to represent the fuzzy sets.

Table-2. Fuzzy rules for fuzzy logic controller

	Fuzzy rules
1	*If (dc_r is pos_L) then (Pbat is neg_L)(Psc is zero)(1)*
2	*If (dc_r is pos_S) then (Pbat is neg_S)(Psc is zero)(0.5)*
3	*If (dc_r is zero) then (Pbat is zero)(Psc is zero)(1)*
4	*If (dc_r is neg_S) and (Sc is not Over) then (Pbat is zero)(Psc is pos_S)(1)*
5	*If (dc_r is neg_L) and (Sc is not Over) then (Pbat is zero)(Psc is pos_L)(1)*
6	*If (dc_r is neg_S) and (Sc is Over) then (Pbat is pos_S)(Psc is zero)(0.51)*
7	*If (dc_r is neg_L) and (Sc is Over) then (Pbat is pos_L)(Psc is zero)(1)*
8	*If (P_load is large) and (Sc is not Under) then (Pbat is zero)(Psc is neg_L)(1)*
9	*If (P_load is small) and (speed is high) and (Sc is not Under) and (slope is not up) then (Pbat is zero)(Psc is neg_S)(0.25)*
10	*If (P_load is neg-zero) and (speed is low) and (Sc is not Under) and (slope is not up) then (Pbat is zero)(Psc is neg_S)(0.05)*

The fuzzy logic controller in this study has seven input and two output variables. The seven inputs are: (1) output voltage of hybrid source error (dc_rr), (2) load power (pload), (3) speed,

(4) supercapacitor voltage (ucap), (5) maximum value of speed (speed2), (6) maximum value of supercapacitor voltage (Ucap^2), and (7) slope. The slope is set to 0 in this study since the drive cycle already includes almost all major conditions of driving. The output variables in this study would be the selection of power from either battery or supercapacitor based on certain conditions. Specifically for this fuzzy logic controller, the output variables are: (1)

battery power (bat) and (2) supercapacitor power (sc).

Model of the fuzzy logic controller as in Matlab/Simulink is shown in Figure 1.

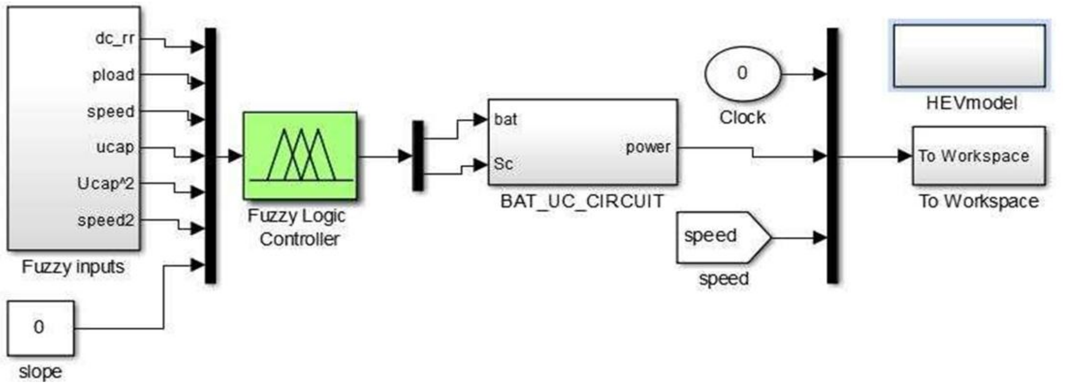

Figure-1. Model of fuzzy logic controller for hybrid electric vehicle

5. RESULTS AND DISCUSSION

The fuzzy logic controller model has been simulated in Matlab/Simulink for duration of 810 s and has produced results shown in Figure 2 to 7.

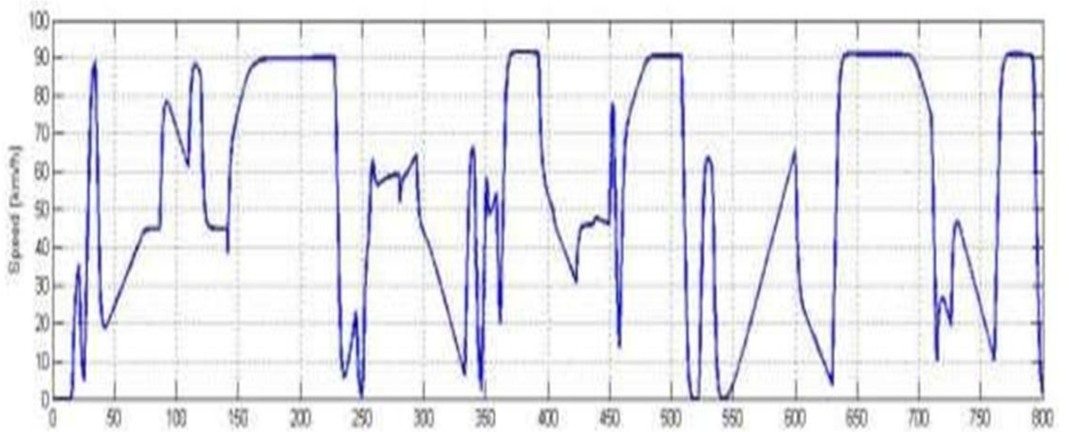

Figure-2. Speed profile or driving cycle

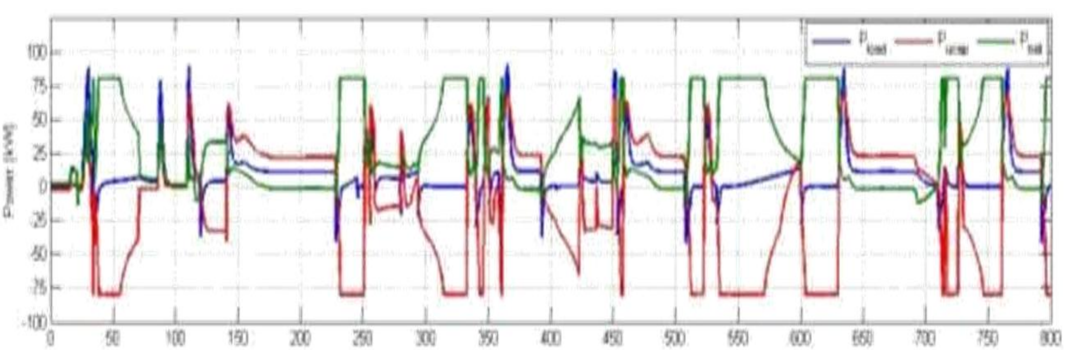

Figure-3. Simulation results for load power, capacitor power, and battery power

It can be seen from Figure 2 and 3 the relation between speed and power is very close. The accelerating point will produce peak in power, where else constant speed representing cruising driving mode will produce zero power. Results show that the battery and supercapacitor are feeding power alternatingly and this is due to that the parameters have been set to charge and discharge only one energy source at one time.

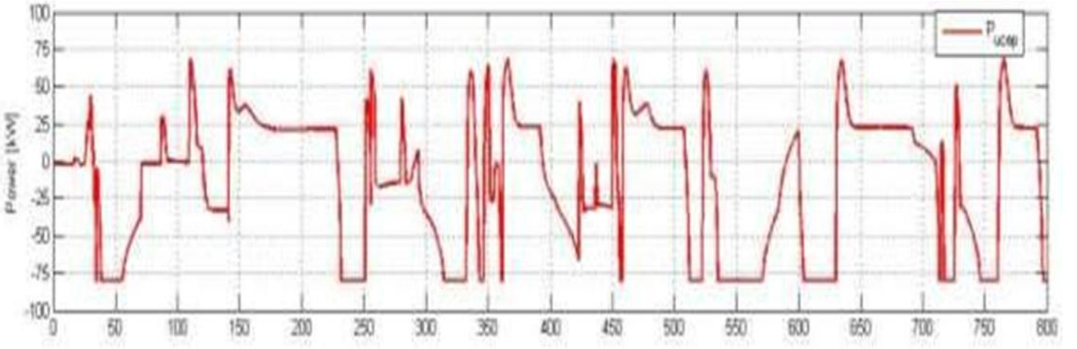

Figure-4. Simulation results for capacitor power

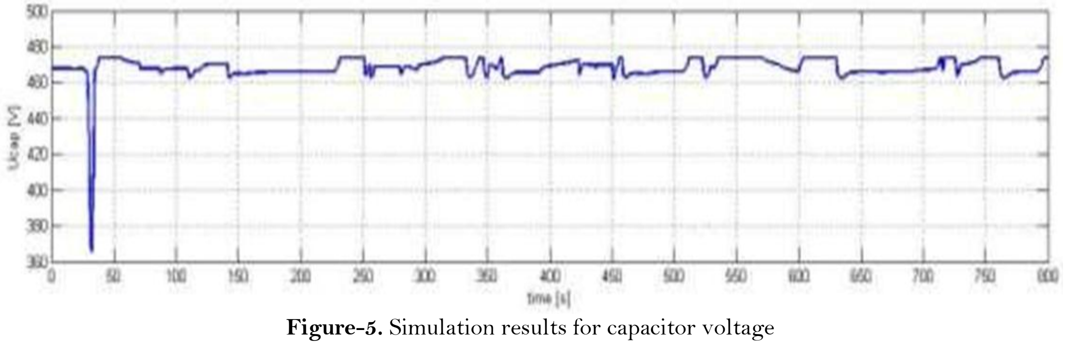

Figure-5. Simulation results for capacitor voltage

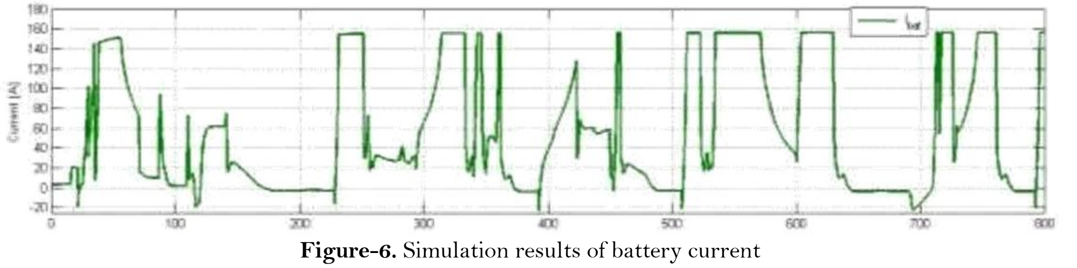

Figure-6. Simulation results of battery current

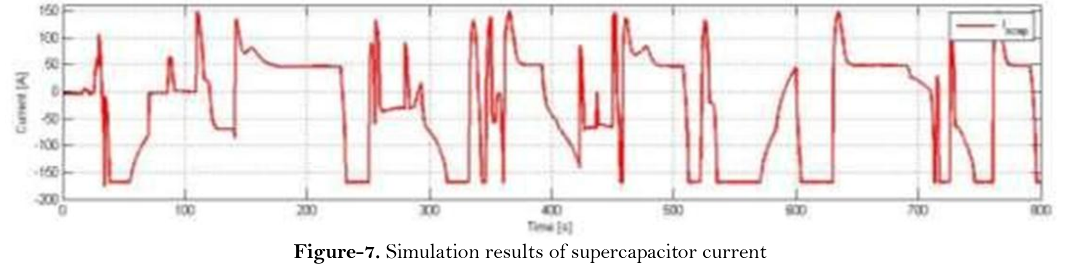

Figure-7. Simulation results of supercapacitor current

Figure 4 demonstrates the capacitor power which is apparent that the supercapacitor is charging and discharging. Figure 5 shows the voltage of the supercapacitor which only drops from 470 V to 370 V during the 30 s simulation time. It is due to the acceleration from 10 to 90 km/h which happened at the same time. However, it can be seen that once the battery and supercapacitor has started operating continuously charging and discharging, the supercapacitor voltage is maintained at about 470 V. Considering the energy management system is to manage energy feed between battery and supercapacitor, these results of battery and supercapacitor current as displayed in Figure 6 and 7, show that the energy management system which embeds fuzzy logic controller is operating successfully.

There are limitations though for this hybrid electric vehicle's fuzzy logic controller simulation. Among the limitations is that the simulation is done for duration 810 s only which is due to the fact that the driving cycle is set for that duration only. This study also does not consider mathematical formulations of the hybrid electric vehicle. Thus, the variables are limited to static response and not taking dynamic response into consideration. The study also does not consider the feasibility of the whole system. These limitations could be taken into consideration for future development in improving this fuzzy logic based energy management system for hybrid electric vehicle.

6. CONCLUSION AND RECOMMENDATION

The fuzzy logic controller in this hybrid electric vehicle is designed to manage energy feed between energy storage devices of battery or supercapacitor. Based on the results shown, the fuzzy logic controller is working as it is expected, with the power feed from either battery or supercapacitor is sufficiently feeding the load or required power. Both battery and supercapacitor is also operating one energy source at a time. The idea of having battery and supercapacitor is to extend the lifetime or life cycle for both devices; an effort to reduce the long-term maintenance cost. Yet, an extended study from this current one, such as feasibility or dynamic response study, is still to be recommended in order to show efficiency of this fuzzy logic controller.

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