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Energy Management in Series-Parallel Hybrid Electric Vehicles Using Fuzzy Logic Controller

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Abstract

This paper describes and introduces a nonlinear model for series-parallel Toyota Prius hybrid electric vehicle (HEV). Required information of driving cycle has been extracted with using Advisor simulation software. Due to optimum power split, we proposed a fuzzy logic compensator that has the duty to split power between energy sources. This compensator help set of planetary gears in order to achieve that goal in accordance to instantaneous power changing. The simulation results of the control strategy, it turns out that our proposed approach raises the efficiency of costs.

Keywords: hybrid electric vehicle, series-parallel model, Advisor simulation software, fuzzy controller

1. INTODUCTION

Nowadays, encountered with increasingly more resource and environmental problems, people have to pay more attention to the fuel economy (FE) and the emission of transportation such as vehicles. Developing a vehicle with lower fuel cost and lower emissions has become a goal of current vehicle industry [1] , [2]. In HEVs combustion engine works as the primary energy source and batteries will automatically work as auxiliary source in case of too much power demanding. In normal working condition, extra energy is stored in batteries through dynamo which result in improving fuel consumption [3]. The control strategy of HEV can be classified into two types: rule based method and optimization strategy. The first type of strategy usually is based on heuristic information and has some predefined rules. This strategy is simple and easy to implement in real time systems. Although this strategy can be implemented with fuzzy logic principles [4]. The second type of strategy will compute optimal power split based on cost function which is defined in accordance to fuel consumption value. Dynamic optimization approach such as genetic algorithm are popular in HEV controlling systems. Due to dynamic inherent parameter of the HEV, choosing dynamic programming seems to be more logical, but this algorithm needs future condition of driving cycle which is not available in real application. Some control strategy have the ability of working real time [5]. There are some intelligent algorithm that defined their rules based on extracted information. Furthermore previous researches have been showed that changing path direction will effect on fuel consumption [6]. Some constraint such as level of available source's energy and drivability should be considered. Drivability will be low in case of too many off and on of combustion engine [7]. Dynamic programming algorithm has been proposed with a model predicting controller [8]. In this paper a time dependent model change into a model with dependence on driving path. A GPS used in order to obtaining future information of driving conditions. A controlling procedure based on fuzzy logic is proposed for reducing Nox with balancing charge of batteries level [9]. Velocity of electric motor and force value on accelerator pedal are selected as inputs of controller. They reduced the amount of produced Nox, but their work could not guarantee the balance of battery's charge level. In [10] two individual fuzzy logic controller have been presented for overcoming this problem. A power balance controller used velocity of vehicle and motor velocity as input which hold the charge of batteries in a desire level by producing proper torque.

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In [11] , [12] fuzzy controllers are proposed under different conditions with the goal of optimum power management. In [13] a fuzzy logic system have been proposed which was named as 'environmental awareness driving'. Four DIE, DSI, FTD and SOC factors have been infused in order to distribute effective torque between electric motor and combustion engine.
Many investigations have been done about cost reduction of HEVs. Most of them only considered velocity and torque. However, choosing proper input and output of fuzzy controller could lead to a better cost reduction. In addition, sudden velocity changes in combustion engine will waste fuel. In this paper besides current demanded velocity and torque from driver, the past state of velocity and torque changing are also considered as other inputs. Furthermore, all controllers in this work are fuzzy logic controllers.
This paper will be organized as follows: in section 2, a nonlinear of our model for HEV dynamic system will be proposed. In section 3, fuzzy compensator and related fuzzy principles will be discussed with some simulation results. Finally, section 4 concludes of this paper.

2- A NONLINEAR MODEL FOR OF DYNAMIC SYSTEM FOR SERIES-PARALLEL TOYOTA PRIUS HYBRID ELECTRIC VEHICLE

We consider a series-parallel Toyota Prius HEV and required information about the vehicle and driving cycle are obtained by Advisor simulation software [14]. Instead of a single gear system a set of planetary gears are implemented in series-parallel HEVs. This system provide the connection among all energy sources. Besides, this system consist of a sun gear, some planetary gears and a ring gear. Planetary gears start moving with the movement of sun and ring gears. Demanded power will be managed proportional to the sun and ring gear ratio among energy sources. The mathematical equations for each energy source can be written as follows:

$$\begin{aligned}
\dot{T}_{r,g} &= \left[-\frac{tx_{pg,s}}{tx_{pg,s}+tx_{pg,r}}\right]\times T_{a,r}\\
\dot{T}_{r,m} &= T_{r,r}-\left[\frac{tx_{pg,r}}{tx_{pg,s}+tx_{pg,r}}\right]\times T_{a,r}\\
\dot{T}_{a,r} &= \left[\frac{tx_{pg,r}}{tx_{pg,s}+tx_{pg,r}}\right]\times T_{a,r}\times T_{r,m}\\
\dot{\omega}_{r,g} &= \left(\left[1+\frac{tx_{pg,r}}{tx_{pg,s}}\right]\times \omega_{r,g}\right)-\left[\frac{tx_{pg,r}}{tx_{pg,s}}\times T_{r,m}\right]
\end{aligned} \tag{1}$$

Where parameters for model (1) is given in Table 1.

Table 1: parameters for model (1)

$tx_{pg,s}$	Number of sun gear tooth
$tx_{pg,r}$	Number of ring gear tooth
$T_{r,r}$	Required torque from ring gear
$T_{r,m}$	Required torque from electric motor
$\omega_{r,g}$	Speed of the electric motor
$T_{r,g}$	Required torque from generator
$T_{a,r}$	Torque of the ring gear

3- FUZZY COMPENSATOR AND SIMULATION RESULTS

Due to the operation of HEV and optimum power split between electric motor and combustion engine, we propose a fuzzy compensator. In this controlling strategy we identify each motion and declare the proper rules based on those motions. For instance the compensator will transfer more energies to the generator when vehicle brake.

Demanded current and past velocity and torque from sets of planetary gears are selected as fuzzy compensator inputs. Demanded velocity form each sources (electric motor, combustion engine and generator) and essential instantaneous variations in torque are considered as outputs. In according to inputs variation and state of charge, the fuzzy compensator will adjust the required velocity and torque for each energy source.

In HEVs electric motor is working in low speed operations of vehicle. Combustion engine will work at medium and high speed conditions. However at very high speeds both of engines will be made the vehicle move. About 150 rules are used in fuzzy compensator where some of these rules are presented in Table 2. Furthermore, Results of simulations are described below.

Figure 1 illustrated the fuel usage values with and without using of fuzzy compensator. As we can see in figure1, an acceptable improving in fuel consumption is obtained by using fuzzy compensator. In the same way Figure 2 shows state of charge (SOC) which is clear that using fuzzy compensator leads to a better SOC.

Table 2: some examples of imposing rules to fuzzy controller

T_{rf}	ω_{rf}	$T_{rf}(t-1)$	$\omega_{rf}(t-1)$	SOC	ΔT_e	$\Delta\omega_e$	ΔT_g	$\Delta\omega_g$	ΔT_m	$\Delta\omega_m$
Very Negative	Medium	Low Negative	Medium	Medium	Low Negative	Low Negative	Low	Low	Zero	Zero
Low Negative	Low	Low Negative	Low	Low	Zero	Zero	Low	Low	Low Negative	Low Negative
Low Negative	Medium	Medium Negative	Very	Medium	Low Negative	Low Negative	Low	Low	Zero	Zero
Low	Low	Zero	Zero	Medium	Zero	Zero	Zero	Zero	Low	Low
Low	Low	Low	Zero	Medium	Zero	Zero	Zero	Zero	Low	Low
Very	Very Much	Very	Very	Medium	Zero	Zero	Low Negative	Low Negative	Low	Low

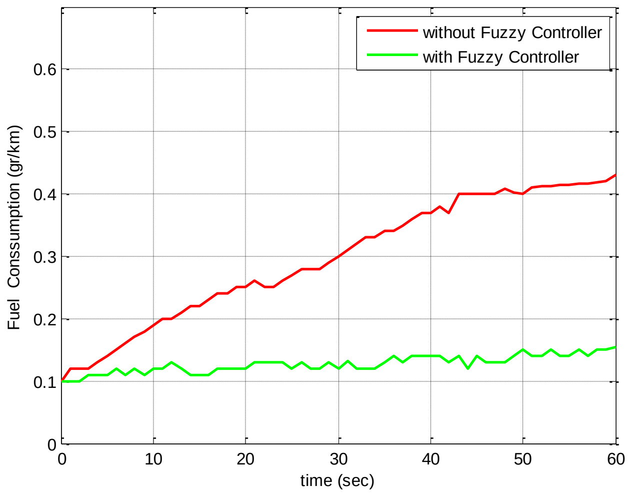

Fig1: fuel usage graph with and without using fuzzy compensator

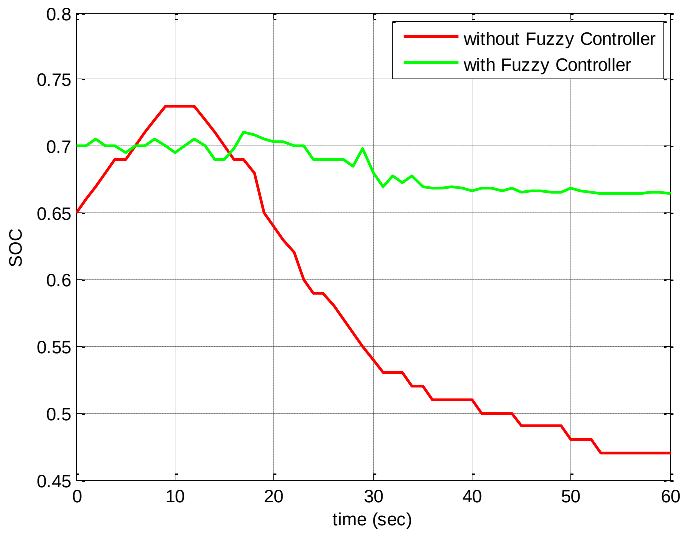

Fig2: state of charge graph with and without using fuzzy compensator

4- CONCLUSION

In This paper we selected a series-parallel Toyota Prius HEV and required information about the vehicle and driving cycle are obtained by Advisor simulation software. Then with a fuzzy controller the cost of vehicle has been minimized with considering two fuel consumption and state of charge factors. The results demonstrate that the proposed technique with new fuzzy compensator is very suitable for reducing vehicle costs.

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