Fuzzy Driver Command Interpreter for Parallel Hybrid Vehicle

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***Abstract*— In order to exploit the advantages of parallel hybrid vehicles, it is necessary to develop a control strategy that typically implements a high-level control algorithm. This algorithm determines the appropriate power split between the electric motor and the engine to minimize fuel consumption and emissions, while staying within specified constraints on drivability, reliability, battery charge sustenance. Moreover, the control strategy should be adaptive to track the demand changes from the driver or drive cycle for optimization purposes. The energy in the system should be managed in such a way that: the driver inputs i.e. from brake and accelerating pedals are satisfied consistently. In order to fulfill these conditions, there is a need to develop an efficient control strategy, which can split power based on demands of the driver and driving conditions. Hence, for optimal energy management of PHEV, interpretation of driver command and driving situation is most important. In view of this, a fuzzy logic based strategy for interpretation of driver command is proposed in this paper.**

Key words: Hybrid vehicles; fuzzy logic, driver command; parallel hybrid vehicles

I. INTRODUCTION

Recently, environmental problems are the real issues to concentrate and automobile industry are also trying hard to utilize the technology that is friendly to nature. There is a partnership between the United States government and the automotive industry, with the target to develop a new generation eco friendly vehicles to resolve environmental issues (15). The emissions of normal Internal Combustion Engine (ICE) are held responsible to major extent for pollution through automobile. Therefore the researchers are concentrating towards replacing internal combustion engine by another power source to resolve global warming issues. Therefore there is a necessity to develop the energy management strategy to split the power based on driver command and driving conditions. Till now the overall design approach are divided in four different categories- based on gathered information a rule base is generated, computational method, programming based techniques and intelligent control strategy were used to split power between two sources with a comprehensive performance. Baumann developed a rule based control strategy [7]. Fuel economy improvement with a fuzzy controller was demonstrated in Salman and schouten which deals with fuel economy problem [8][9]. Syed proposed another system for improving fuel economy and form a fuzzy rule based using advisor. Recently a neurocontroller was employed in a hybrid electric propulsion system of a small unmanned aerial vehicle which proves significant energy saving [12]. Information from past and present were used and heuristic rules were formed by Hoffman[13]; Lin and Schouten proposed a system based upon the observations obtained with the PMP an dissolved in real-time[14] [16] Borhan get optimized result [17]. Frequently, the estimation of the multiplier is based on feedback on the current battery state-of-energy using a constant reference [18].

The objective of this paper is to develop an energy management strategy for a parallel hybrid electric vehicle (PHEV) that optimizes the fuel consumption and resolves emission problem. Hence, for optimal energy management of PHEV, interpretation of driver command and driving situation is most important. In view of this, a fuzzy logic based strategy for interpretation of driver command is proposed here. The driver command depends on two parameters namely, 1. Driving pattern and 2. Driving Situation. Driving pattern is the speed profile of vehicle where as driving situations are based on traffic environment by considering parameters like the type of roads and driving ability of driver, trend of driving and mode of driving. The numeric values of these parameters will be taken from the literature in order to model the driver command interpreter and generate the fuzzy rule base. The output of this interpreter will help the intelligent control system to split the power generated by IC engine into propulsion power and charge sustenance. The proposed strategy will be developed using fuzzy logic toolbox of MATLAB. The effectiveness and utility of the proposed system will be demonstrated by simulating one driving condition and analyzing the results.

II. PROPOSED HYBRID VEHICLE CONFIGURATION

Hybrid electric vehicles (HEVs) have a potential to reduce fuel consumption and environmental pollution. HEVs have become one of the best option to replace conventional vehicles which has internal combustion engines (ICE) is the only power source [4]. HEVs incorporated of two energy converters to generate the power required to drive the vehicle and balance the torque requirement. The architecture of parallel hybrid vehicles includes an ICE with comprise of fuel tank and an electric machine with comprise of energy storage battery [1]. For both the accelerating and deceleration configuration, there are four different ways to operate the system, depending on the flow of energy or power: 1) ICE only supplies power to the wheels in both upstream and downstream configurations; 2) only the Electric motor supplies power to the wheels; or 3) both the ICE and the EM concurrently provide power; 4) EM works as generator and some part of ICE is used to charge the battery and some power is used to drive the wheels. A demand of power controller is to manage the flow of energy between all components, while considering the knowledge of condition of battery charge available in the battery [11][12]. The power controllers capable of switching between two in proper way so that overall performance of the vehicle remains same, while at the same time optimizes the performance of the individual power source. This is definitely an increased complexity not found in conventional vehicles containing internal combustion engine only. The task of any hybrid vehicle is to provide the appropriate power to flow between two sources. Moreover, in order to improve the system, to improve the fuel economy and to reduce the emissions of hybrid vehicles, it is important to optimize not only the architecture and components of the hybrid vehicles, but also the energy management strategy. It is necessary to implement the energy management strategy that optimizes the operation of the overall hybrid system based on instantaneous vehicle information [15][16]. The proposed energy management approach for control of vehicle using fuzzy logic is presented in the Figure 2. The fuzzy logic control is very suitable for controlling hybrid vehicle as it is a good method for realizing an optimal tradeoff between the efficiencies of all components of the PHV[8][10]. Fuzzy logic control is tolerant to imprecise measurements and to component variability. It also gives a systematic methodology for the development of a rule-based energy management strategy [6][7][8].

From review of literature presented above, it is obvious that the complex architecture of parallel hybrid vehicle demands for an efficient methodology to switch the power between two sources that is battery and IC engine. Such methodology must be robust enough to accommodate the variations in the driver command and road conditions while driving the vehicle. For this purpose, a fuzzy logic based control system is proposed in this work. The main goal of this controller is to distribute the required torque as desired. The architecture of HEV used in this work is presented in the Figure 1. From this figure, it can be observed that the IC engine and battery are placed parallel to each other. The transmission system gets the power from the selected source and transmits it to drive system further for the propulsion of the vehicle. The proposed fuzzy logic based system is designed to infer about the power source to be utilized based on the driver command only. Additional parameters like state of charge of battery and electric motor are not considered in this work.

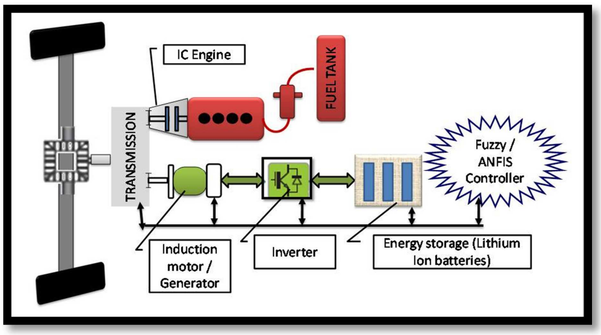

Fig.1 The schematic of proposed hybrid system

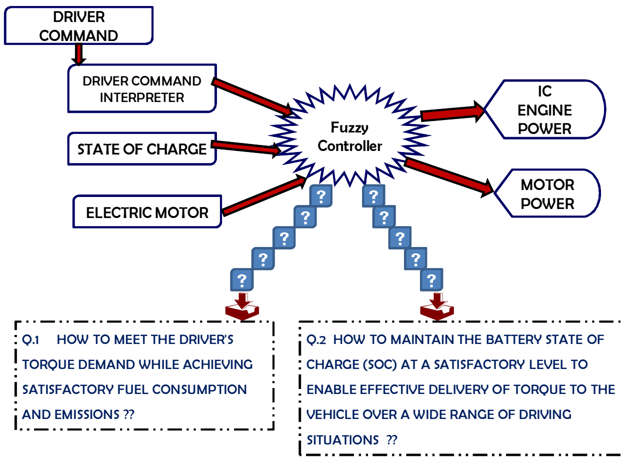

Fig.2 schematic of fuzzy logic controller

III. Basis Of Fuzzy Rule Base

The schematic of fuzzy logic controller given in the figure 2 shows that fuzzy controller requires information about driver command , state of charge of battery and condition of electric motor to take a decision whether propulsion power is to be derived from IC engine of electric motor. Among the input parameters, most important input is the driver command reception and its interpretation. In this paper, a fuzzy logic based driver command interpreter is suggested. The output of this interpreter will pose the torque requirement to the overall control system. The driver command of fuzzy controller depends on two important factors namely (1) Driving pattern and (2) Driving situations. Driving pattern is the speed profile of vehicle where as driving situations are based on traffic environment.

Driving Pattern: It deals with speed characteristics of vehicle in particular environment conditions [3]. While there is no presice definition of these parameters, a number of studies have done to define a list of such parameters [26]. E. Ericsson [27] has given up to 62 characteristic parameters to be extracted from a given drive cycle, which she has further divided into 16 groups or factors. Out of these 16 groups, she has suggested following 9 factors given in Table 1 were to be considered vital.

Table 1: Parameters for driving pattern

Factors	Description
1)	Deceleration factor (avg. deceleration)
2)	Factor for acceleration with strong power demand
3)	Stop factor (% of time ν < 2 Km/hr)
4)	Factor for acceleration with moderate power demand
5)	Low speed factor (% of time when ν is between 15-30 Km/hr)
6)	Mid speed factor (% of time when ν is between 50-70 Km/hr)
7)	Mid high speed factor (% of time when ν is between 70-90 Km/hr)
8)	High speed factor (% of time when ν is between 90-110 Km/hr)
9)	Extreme High speed factor (% of time when ν > 110 Km/hr)

In the proposed work, these 9 driving pattern parameters are further grouped into three input parameters for the generation of fuzzy rule base and is the fuel consumption. These three input parameters are 1. Speed 2. Stop factor and 3. Average Acceleration. The speed is considered in four levels low (15-30 km/hr), medium(30-70 km/hr), high(70-90 km/hr) and very high (90-110 km/hr). The stop factor is considered in three levels i.e. stop factor equal to zero, equal to 2 and between 2 and 25. The average acceleration is considered in three levels i.e. zero, 0-0.165 and -0.165 to 0. The output parameters are the fuel consumption and three levels are considered i.e. low, medium and high. Based on this information, 19 rules are formed. These 19 rules are utilized to infer about fuel consumption based on the levels of the input. This gives driving pattern.

DRIVING SITUATION: It determines overall traffic condition including the vehicle's operating mode so considers Roadway Type, Driver Style, Driving Trend, and Driving Mode. Basically driving situation is categorized in above four types to decide the situation at that instant.

Roadway Type: The roadway type directly governs the fuel consumption. It is a quite optimized measure describing operational conditions occuring in a traffic. It deals with Speed of the vehicle, Time of traveling, and Freedom to driver, Traffic disturbance, Comfort, and Convenience. Hence, roadway type is classified based on level of service. The roadway type identification needs information about average velocity, number of stop factor and speed of the vehicle. 6 roadway types are given in [29]. LOS A -Best Operating Conditions i.e. High Speed Freeway, LOS B - Good operating conditions, LOS C - Moderate Operating Conditions, LOS D - Worst Operating Conditions, LOS E - Ramp LOS F - Arterial Roads. The three levels of average velocity are below 40 km/hr, between 40 to 50 km/hr and between 50 to 90 km/hr[29]. The levels of stop factors and speed are considered same as of driving pattern. Based on the available information from the reference [29], 38 rules were framed. These rules were utilized to predict the type of the roadway.

Driver style: It can be predicted from the temperament of the driver and it is analyzed using average acceleration and ratio of acceleration standard deviation and average acceleration. Many researchers adapt this relationship. The reason is temperament can be analyzed from the instantaneous change in the velocity and the spread of this temperament when observed over a period. Three types of driver styles are identified in the literature 1. Calm 2. Normal and 3. Aggressive [28]. The levels of average acceleration considered for this study are 0 to 0.4884 m/s^2, 0.4884 to 0.7029 m/s^2 and 0.7029 to 0.9027 m/s^2. The levels of standard deviation of acceleration are 0 to 0.1, 0.1 to 0.4 and 0.4 to 0.8. This data was used to generate 9 rules to predict the driving style of the driver.

Driving trend: It is used to assess the short term or transient features of the drive cycle, such as low speed cruise, high speed cruise, acceleration/deceleration, and so on. These transient effects on driving trends can be described by the magnitudes of the average speed (vavg) and acceleration (aavg) values [27]. Cruising is nothing but running the vehicle at apparently constant velocity. It depends on values of average velocity and average acceleration. These two parameters are utilized to understand the cruise condition and change in the velocity. The three levels of average velocity are zero, less than 40 km/hr and greater than 40 km/hr. the three levels of average acceleration considered are zero, -0.5 m/s^2 and +0.5 m/s^2. These parameters are utilized to predict whether driving trend is no cruising, low speed cruising and high speed cruising and change in velocity is zero, positive or negative.

Driving Mode: The instantaneous operating mode of the vehicle every second is the representation of the driver's intention for the propulsion of the vehicle, such as start-up, acceleration, cruise, deceleration (braking), and stationary. From the viewpoint of energy management for parallel hybrid vehicles, for each mode different energy management strategies are required to control the flow of energy in the drive train and maintain adequate reserves of energy in the electric energy storage device [14] to improve the performance of the vehicle. The driving mode depends on the information regarding speed of the engine and the torque requirements. The Engine Speed is to be maintained to maintain the desired speed and is torque required for maintaining vehicle speed constant while overcoming road load and torque required for acceleration or deceleration i.e. driver's intentions, whereas torque of the vehicle is the sudden requirement by the driver to accelerate or decelerate (driver's intention). The two levels of engine speed are zero and greater than zero. The torque is considered in three levels i.e. zero, positive and negative. Based on this information 5 rules are formed and decision about the driving mode can be made. The driving mode can be startup, acceleration, deceleration, cruising and stand still or stationary with no engine running.

IV. Sample Example

In order to evaluate the performance of the proposed system to interpret driver command, three different cases are considered. These cases are from considered from the available data that depicts real life situations. The proposed approach is implemented using Fuzzy toolbox of MATLAB. The 'mamdani' method is used for fuzzification, AndMethod='min', OrMethod='max', ImpMethod='min', AggMethod='max' whereas defuzzification is done using 'centroid' method. The membership functions used are triangular and Gaussian. A user interface is generated which asks various questions to the user and takes input from the user. These inputs are further fed to the .fis file to obtain the matching rule. This matching rule is fired as a solution stating the levels of the input as corresponding output.

Case Problem

The input to the driver command interpreter obtained is given in the Table 2.

Table 2 Input and Output for Case Problem

Input Parameter	Value of input	Output of interpreter
Speed of vehicle	30km/hr	Driving Pattern : low consumption
Stop factor	Zero	Driver Style: calm
Avg. acceleration	0.1 m/s^2	Driving Mode: cruising
Std. deviation	0.1	Roadway type : LOS B
Engine speed	600 rpm	
Torque required	80 Nm	

These inputs were given to the fuzzy driver command interpreter program. For this set of inputs, the outcome of interpreter was Roadway type: LOS B, Driver style: Calm, Driving Mode: Acceleration, overall Driving Pattern: Low fuel consumption. The discussion about these results is as follows:

Since the magnitude of speed is small i.e. 15-30km/hr and number of stop factors are zero for total travel time to 60 seconds with the magnitude of acceleration 0-0.165m/s^2 during driving through same travel distance then using above mentioned data the prediction of MATLAB program is the **"low fuel consumption."**

It is convinced from the observation of roadway type if speed is limited to 15-30km/hr and numbers of stop factors are limited to zero with velocity of 40km/hr then roadway type will be considered by the system as LOS B i.e. moderate operating condition for driver. To identify the driver style average acceleration and standard deviation are used. Standard deviation (SD) is one of indices of variability that can be used to characterize the dispersion among the measures in a given group of samples. Acceleration criteria for determining driver's style are used for specific driving time of 60 sec, average acceleration to be considered as 0.1 m/s^2 and standard deviation is 0.1 then driver style will be declared as calm driver. The purpose of driving trend is to assess the changing features of drive cycle such as low/high speed cruise acceleration/deceleration and stop/idle. These transient features of driving trend can be described by magnitude of average speed and average acceleration if the values for speed is 30 km/hr and acceleration is 0.1 m/s^2 then drive cycle is assess as Low speed cruise acceleration. The instantaneous operating mode of the vehicle every second is the representation of the driver's intention for the operation of the vehicle, such as start-up, acceleration, cruise, deceleration idle/ stationary. Driving mode determines current operating mode of vehicle. The recognition of driving modes of the vehicle instantaneous speed and torque require for acceleration and deceleration. If speed is greater than zero and torque is positive i.e. during acceleration condition then driving mode gives output as cruising condition.

V. Observations

A fuzzy logic based system is developed to predict the driver command for the operation of parallel hybrid electric vehicle. This system utilized the data available in the literature to generate the rule base. When the complete system was implemented to case problem, it was observed that the solution predicted by the system is nearly same as of answers given by the truth table / gathered information. The main observation was that when numbers of rules are more, the system gives better answer as compared to less number of rules. At few experiment, it was found that changing the membership function from trapezoidal to triangular improved the performance of the system. The major aspect of this developed system is that user has to have correct knowledge about various parameters like instantaneous speed, average velocity, average acceleration, engine speed and engine torque. This aspect makes the system highly suitable to interface with real-time hybrid vehicle and various sensors. The output of the proposed system is the intermediate output of the whole control system for efficiently driving hybrid electric vehicle. However, it is the most important aspect since driver command is going to decide the action to be performed by the controller and other qualitative parameters like fuel consumption, ride comfort and mileage.

VI. Conclusion And Future Scope

The developed fuzzy logic based system for driver command interpretation for parallel hybrid electric vehicle predicts the probable driver command based on various conditions like roadway type, driving mode, driving trend and driver style. The output of this system is vital for driving the hybrid vehicle and selecting the mode of engine operation. For this, torque requirements, and information regarding state of charge of the battery are to be clubbed which will give a complete control action to optimally utilize the power source, i.e. IC engine and battery. This developed system is an intermediate part of the whole control system and hence when clubbed with engine performance parameters, electric motor parameters and state of charge for battery then can be simulated using dynamics of vehicle in the MATLAB environment.

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