Energy Management of Hybrid Vehicle using Artificial Intelligence for Optimal Fuel Efficiency

S.L. Badjate, Zoonubiya Khan Ali, R.V Kshirsagar

Abstract: In general, hybrid systems can be commanded by splitting the required power between the electric machine and ICE to meet the specific needs like fuel consumption, efficiency, performance, and emissions. This power splitting scenario, which is the key point of hybridization, is in fact the control strategy or energy management of the hybrid automobile. Performance of the system, therefore, depends on the control strategy which needs to be robust (independent from uncertainties and always be stable) and reliable. Moreover, in order to improve the system, the control strategy should be adaptive to track the demand changes from the driver or drive cycle for optimization purposes. 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.

Keywords: Hybrid vehicles, fuzzy logic, driver command, parallel hybrid vehicles.

I. INTRODUCTION

The global scenario of environmental conditions is very alarming. The continuous and uncontrolled use of fossil fuels is responsible for deterioration of the habitat. The large number of vehicles around the world has caused and continues to cause serious environmental problems and health issues for human. Air pollution, global warming and rapid depletion of the earth's petroleum resources are now problem of paramount concern. More and more countries all over the world are contributing towards development of greener vehicles with the ultimate objective of eliminating hazardous tail pipe emissions. HEV (Hybrid Electric Vehicles) have thrives as a lucrative solution to the above mentioned global crises. HEV achieves superior mileage and low exhaust emissions as compared to conventional Internal Combustion Engines (ICE). HEV is a term used to describe vehicles that use ICEs in combination with one or more electric motors (EM's) connected to battery pack as a secondary energy storage system. Providing propulsion to the wheels either together or separately **[Ehsani, et al (2005)]** [1]

The proposed MFIS based EMS is a holistic approach which consider all the important modules require for efficiently managing energy in PHEV. The driver command interpreter is the important aspect of driving considered in this work. Most of the previous approaches have not given any consideration to this vital aspect.

The proposed MFIS based strategy is implemented in this paper to various Driving Cycles and it was observed that the proposed methodology works well for any type of driving cycle irrespective of its length, speed profile and variety of road.

II. LITERATURE REVIEW

With the advent in automobile engineering, integration of embedded system and sophistication in programming, the complex configurations of hybrid vehicles are coming in the market. However, these configurations are inspired from the classical configurations. The energy management systems are always at the heart of HEvs. These systems are responsible to reduce fuel consumption and tailpipe emissions. There are two types of EMS based on mode of operation

a) Online mode of operation
b) Offline mode of operation

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Table 1 show online and offline methods and their comparison [Sabri et al (2016)] [2]

Reference	Modeling approach	Major Findings	Type of EMS
Huang et.al.(2011)[3]	Statistical analysis & machine learning with neural network (**parallel HEV)**	i) Automatically discriminates driving condition in real time. ii) fast computation type for online implementation	On-line EMS
Murphey et.al.(2013)[4]	Machine learning frame work using optimal solution from dynamic programming **(series parallel HEV)**	i) Three online intelligent energy controller was proposed. ii) high performance regardless of initial SOC value iii) Increased fuel saving ranging between 5%- 10% depending roadway type & congestion level.	On-line EMS
Di cairano et. al.(2013)[5]	Model predictive control with proper smoothing algorithm **(Series HEV)**	i) Improved power train efficiency by regulating engine transients ii) Low computations burden for online implementation. iii) Improved fuel consumption over rule based EMS	On-line EMS
Di cairano et. al.(2014)[6]	Stocasting model prediction control and machine learning with quadratic programming **(Series HEV)**	i)Driver aware energy management controller ii) quadratic programming handles layer state direction models while reconfiguring in real time depending on changes in driver behavior	On-line EMS
Zhang et.al.(2014)[7]	Multi objective non linear programming & genetic algorithm **(Parallel HEV)**	i) Varying time domain method used to switch priority of objective based on current vehicle state. ii) Flexible EMS over different driving condition	On-line EMS
Zhang et.al.(2012)[8]	Fuzzy multi objective optimization **(Parallel HEV)**	i) Optimization algorithm simulated total fuel consumption treated as optimization goal ii) A portion of simulated fuel consumption translated over to equivalent electrical energy based on available SOC iii) Improved fuel consumption over rule based and fuzzy logic based EMS	Off-line EMS
Borhan et.al.(2012)[9]	Non linear predictive control **(Series parallel HEV)**	i) Introduction of a second EM/generator for added degrees of freedom ii) EMS division into supervisory and low level controller iii) Systematic and highly predictive EMS	Off-line EMS
Samanta et.al.(2013)[10]	Particle swarm optimization **(Series Parallel HEV)**	i) First known PSO application HEV ii) Optimization problem applicable across HEV, PHEV and also EV	Off-line EMS
Keulen et.al.(2013)[11]	Numerical solution algorithm **(Parallel HEV)**	i) Global optimal power split curve calculation with lesser computational requirement compared to dynamic programming ii) Highly accurate equivalent approximation of optimization compared to dynamic programming	Off-line EMS

III. PROPOSED ENERGY MANAGEMENT SYSTEM FOR HYBRID VEHICLE

Because of the potential of hybrid electric vehicles (HEVs) to reduce fuel consumption and environmental Pollution, HEVs have become one of the best alternatives to conventional vehicles, which are driven by internal combustion engines (ICE) **[Powell et al(1998)[12] Rahman et al(1999)[13]].** HEVs comprises of two energy converters to generate the power required to drive the vehicle and fulfill other requirement. Typically, the architecture of these vehicles includes an ICE with an associated fuel tank and an electric machine with an associated energy storage battery. For both the upstream and downstream configuration, there are four different ways to operate the system, depending on the flow of energy: 1) provide power to the wheels with only the ICE; 2) only the EM; or 3) both the ICE and the EM simultaneously; 4) charge the battery, using part of the ICE power to drive the EM as a generator the other part of ICE power is used to drive the wheels. A power controller is needed to manage the flow of energy between all components, while taking into account the energy available in the battery. The power controller adds the capability for the components to work together in harmony, while at the same time optimizes the operating points of the individual components. This is clearly an added complexity not found in conventional vehicles. Proper management of power flow or distribution of torque is a critical issue for the

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implementation of HEVs. This task is performed by HEV control strategy using fuzzy. The HEV control strategy determines which power source is use according to the driver's torque demand and the specific features of the driving situation. The hybrid electric vehicle considered for this study has architecture as shown in Figure 1.

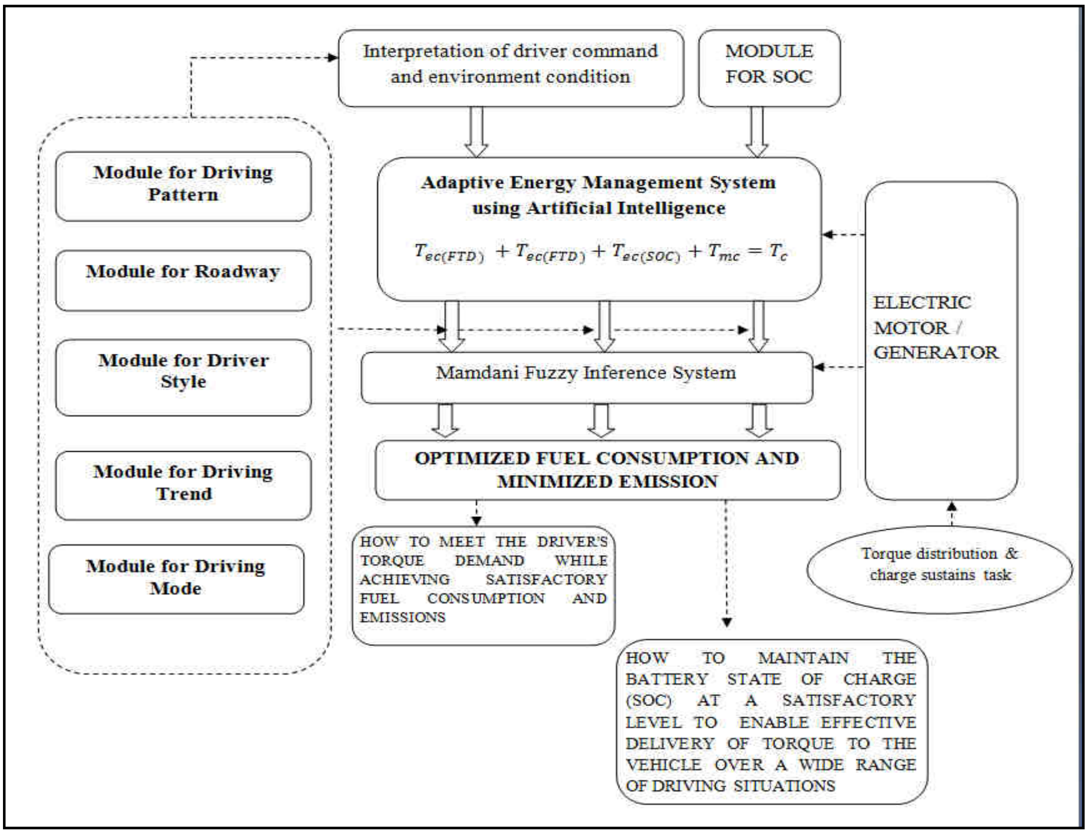

Figure1 Architecture of Proposed Hybrid System

3.1. Driving Pattern

Driving pattern is generally defined in terms of the speed profile of the vehicle in a particular environment [3].The driver command is used to extract the characteristic parameters' of driving pattern. While there is no consensus among researchers as to the precise definition of these parameters, a number of studies have attempted to define a list of such parameters E. Ericsson has given up 9 vital parameters to design driving pattern .These 9 driving pattern parameters are further grouped into three input parameters for the generation of fuzzy rule base and output will be 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.

3.2. Driving Situation

Driving situation is the next section of driver's command, which determines overall traffic environment including the vehicle's operating mode so it has to concentrate on Roadway Type, Driver Style, Driving Trend, and Driving Mode.

3.2.1 Roadway Type

The roadway type directly governs the fuel consumption it is a qualitative measure describing operational conditions within a traffic stream based on service measure. It has to deal with Speed, Travel Time, Freedom to Maneuver, Traffic Interruptions, Comfort, and Convenience. Hence, there are classified based on level of service. The roadway type identification needs information regarding average velocity, stop factor and speed of the vehicle. In all 6 roadway types are identified, 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. The levels of stop factors and speed are considered same as of driving pattern. Based on the available information, 31 rules are framed. These rules are utilized to predict the type of the roadway.

3.2.2. Driver Style

Driver style 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. This relationship is adapted by many researchers. 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 of time. Three types of driver styles are identified 1. Calm 2. Normal and 3.

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Aggressive. 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. Based on the available data, nine rules are generated. These rules will be further utilized to predict the driving style of the driver. It is a style which used to assess the short term or

3.2.3 Driving Trend

Driving trend 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. 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.

3.2.4 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 predict driver command, three different cases are considered. These cases are considered from the available data which depicts real life situations. The proposed approach is implemented using Fuzzy toolbox of MATLAB. The 'mamdani' method is used for fuzzification, And Method='min', Or Method='max', Imp Method='min', and Agg Method='max' whereas defuzzification is done using

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 [39]. Cruising is nothing but running the vehicle at apparently constant velocity.

'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.

4. 1. Case 1

If the magnitude of speed is small i.e. 15-30km/hr and number of stop factors are zero for total travel time of 60 seconds with the magnitude of acceleration 0-0.165m/s^2 during driving through same travel distance then using above mentioned data driving pattern should predict 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 50km/hr then roadway type will be considered by the system as "LOS C" 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 0.375 m/s^2 and standard deviation is 0.1then 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 speed cruise, high speed cruise, acceleration, deceleration, and stop or idle. These transient features of driving trend can be described by magnitude of average speed and average acceleration if the values for speed is 22.5km/hr and acceleration is 0.375 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 or 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 output. So using all above condition of driving pattern, roadway type, driving trend, driver style and driving mode the driver command will interprets as:

a) Low speed acceleration.

b) Calm driving implies anticipating other road user's movement, traffic lights, speed limits, and avoiding hard acceleration.

c) Battery power will be used to propel the vehicle

d) Low power consumption.

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4. 2. Case 2

Fuzzy rule base development starts with the postulate that fuel economy in HEVs operation can be achieved by operating the ICE at the efficient region of the engine and by avoiding transient operations that would occur in a driving situation such as abrupt acceleration and/or deceleration, frequent stop-and-go event, and so on. Through the literature survey [4][9], I investigated the driving pattern factors that affect fuel consumption and emissions and that would be used in the development of the fuzzy rule base at particular situation in specific time of 60 seconds and infer as "Medium fuel consumption" if the magnitude of speed is large of about70-90km/hr and number of stop factors are two with the magnitude of acceleration is same as 0-0.165m/s^2.Fuzzy rule base for roadway type is fired and postulate type of roadway for driving and declare as "LOS E" i.e. ramp type roadway for driving if speed is limited to 70-90km/hr and numbers of stop factors are very high i.e.40 with velocity of 50km/hr. The rule base consists of facility-specific rule sets devised for driver style to produce style of driving as "normal driving" for a given style type if average acceleration to be considered as 0.667 m/s^2 and standard deviation is 0.3. When the vehicle is driving at a constant speed, a small amount of torque is needed to maintain the vehicle speed and to overcome the road load. In the driving mode, including acceleration and cruise mode, additional battery charge by operating the ICE is not suggested because it may cause the overall performance to deteriorate and/or the battery to be overcharged. Selective battery charge operation may be needed for the operation of HEVs in these modes On the other hand; driving trend (i.e., modal transition of the vehicle) is identified with short-term driving data compared with the roadway type identification, since driving trend of the vehicle can change rapidly. Driving trend will predict as high speed cruise if magnitude of average speed and average acceleration if the values for speed is 22.5km/hr and acceleration is 0.375 m/s^2.The recognition of driving modes of the vehicle is made by examining the following condition of speed and required torque and declared as "accelerating mode" if speed is greater than zero and torque is positive i.e. during "acceleration". At each section the fuzzy rule base is fired and generated aforementioned outputs so overall driver command system will interprets following condition by considering the outputs from driving pattern, roadway type, driver style, driving trend and driving mode as

a) High speed acceleration
b) Normal driving mode
c) Battery and IC engine both are used to generate power for hybrid vehicle.
d) Power consumption is medium.

4. 3. Case 3

The mission of driving pattern is to extract the key statistical features, or characteristics parameters, of the driving pattern for fuel consumption and emission problem While there is no consensus among researchers as to the precise definition of these parameters, a fuzzy rule base is generated for driving pattern and it will fired and declare as " high fuel consumption" if the magnitude of speed is large of about 30-70km/hr and number of stop factors are between 2-25 with the magnitude of acceleration is -0.165-0 m/s^2. In the driver command, information about roadway type is used to index a fuzzy rule base paralleling to the given roadway type. Again, roadway type for the driving in particular situation with specific time of 60 seconds and declared type of roadway as "Los C" i.e. moderate operating condition for driving if speed is limited to 30-70km/hr and numbers of stop factors are high as 25.As stated in above sections driver style is used to identify drivers intention or desire of driving in particular situation and declare as" aggressive style" of driving if conditions are as average acceleration 0.833 m/s2 and standard deviation is 0.4. These features of driving trend can be described by magnitude of average speed and average acceleration if the values for speed is 50 km/hr and acceleration is greater 0.5 m/s^2 then drive cycle is assess as "No cruise mode". In the acceleration mode, as well as non-level road driving mode, such as up-hill climbing, power from the battery is used together with the engine power to cope with the high-power demand, consequently resulting in discharge operation. If engine speed is greater than zero and torque is positive then driving mode will be display as "acceleration mode" of vehicle. Using aforementioned interpretation driver command will interprets following results:

a) Sudden gear change
b) Sudden velocity
c) High braking
d) So rash or aggressive driving
e) Therefore high fuel usage.

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 three different cases, 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 number of rules is 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

In recent years HEV has come up as a lucrative and efficient solution for speedily depleting fossil fuels and global warming. However an adaptive and intelligent technology is

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necessary to tap the advantages from the hybrid vehicles. For an effective design of EMS, the parameters required are big in number. Hence, it is necessary to decide the prominent parameters and their relationships using artificial intelligent technique. The main issue in operating HEVs is obtaining balance between limited energy sources and performance optimization. The tradeoff between objectives subject to variety of constraints makes this energy management system a very good candidate for optimization problems

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