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Energy Management System in the Vehicles using Three Level Neuro Fuzzy Logic

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Abstract

This paper has proposed a hybrid electric vehicle that uses intelligent energy management strategy to decrease the energy consumption of the vehicle. Here, the total energy consumption of the vehicle is initially modelled and further investigated to reduce the amount of energy used to be identified as a sum of electrical energy provided by consumed fuels and on-board batteries. In particular, an intelligent controller is proposed in this work to execute its ability to decrease the total amount of energy consumed and improve the energy efficiency of the vehicle. A fuzzy system is utilized in an account supervisory controller to decide the appropriate mode of operation for the system. The part of the proposed work involves development of optimal control strategies by using neuro-fuzzy logic. In order to obtain optimal performance, the controllers are used to regulate vehicle subsystems and set points. The biggest advantage of this work is the reduction in energy consumption and their ability to execute the operation online. Simulink/MATLAB is used to simulate and validate the performance of the proposed work under various conditions and under several dataset values.

Keywords: Fuzzy controller, hierarchical control architecture, power management, hybrid vehicle, energy consumption

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1. Introduction

Environmental pollution and energy consumption are the two major challenges faced by the automobile industry in terms of sustainable development. As the requirement to decrease energy consumption increases, there is an urgent need to positively improve the efficiency of energy utilization [1]. Hybrid electric vehicles are proved to be a promising way to reduce the exhaustion of harmful gases and the utilization of fuel consumption. As the number of power sources in the hybrid electric vehicle increases, it provides more degrees of freedom for controlling the drive train. This is primarily because it makes the delivery of power to the requested driver by using either of the energy sources available or in the possible combination [2]. This additional degree of freedom can be used to decrease pollutant emissions and fuel consumption. Both energy power management and performance of the vehicle are directly related to vehicle fuel consumption [3].

A relationship between fuel consumption and power management optimisation (PMO) [4] on HEV [5] indicates a substantial decrease in the fuel consumption. Moreover, harmful emissions can also be simultaneously curbed. Thus, PMO plays a crucial role in automobile energy saving in order to attain reduced fuel consumption [6]. In [7], the authors have researched dynamic programming to develop an appropriate means of controlling fuel consumption with the assumptions on driving conditions in the future. However, this methodology requires complex computational abilities and is not possible to be directly implemented through dynamic programming [8]. To address these issues, stochastic dynamic programming is chosen to develop appropriate solutions. Similarly, mathematical problem formulation [9] using analytical optimization methods [10] will also be useful in determining a numerical methodology. In [11], the authors have introduced an Energy Management Strategy (EMS) using Pontryagin's minimum principle.

Online EMS for HEV has been incorporated by the authors in [12] and [13]. Here power split strategy is optimised using estimation distribution algorithm. This uses a number of control strategies to maintain the battery of the system. Energy

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management systems in HEVs commonly use rule based control strategies that are simple to incorporate in real time. To balance the power demand between the battery and the engine, rule based EMS will be apt [14]. Using a State Flow (SF) toolbox [15] the rule-based controller [16] can be used for complex structure. The drawback with this methodology is that it requires extensive experimental data and complex engineering skills to build and design the criteria to follow. Moreover, fuel economy doesn't experience a drastic change due to its limited benefits. Authors in [17] addressed this drawback by introducing a fuzzy inference system. The simplicity of the fuzzy system makes implementing them an easy task and is easy to model uncertainty and nonlinearity. On the other hand, the drawback with this system is its inability to adapt to large changes during modelling of the system [18].

However, this issue was addressed by the authors in [19] who made use of Genetic Algorithms (GA) [20] to equip and enhance the fuzzy controller with the help of various fitness functions. The disadvantage with using this methodology is the random convergence of outputs [21]. Moreover, the time consumed by this algorithm is slightly higher when compared with other similar methodologies and are hence not used for many problem statements [22]. Overcoming this advantage, the Artificial Neural Network (ANN) [23] was introduced to decrease the fuel consumption. The use of Artificial neural Network transformed the way in which vehicles worked and are commonly called the black boxes. The primary objective of this paper is the building and experimental verification of a similar framework that can be used to decrease the fuel consumption [24] using fuzzy systems in collaboration with the ANN such that they can be optimally used to balance the performance of each other. A specific vehicle modelling is required to design [25], build and verify a reliable and efficient EMS for the Hydraulic-Electric Hybrid Vehicle (HHEV) [26].

The two major contributions of this paper can be categorized into two:

1. To investigate and observe a reliable model of the HHEV with the help of Simulink/MATLAB software and TruckMaker. The choice of this software is due to its dynamic simulation environment and reliability for the proper

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execution of the work, integrating the performance of the interconnected sub-systems, embedded sub-systems like HP, ICE, HM, EM, battery etc.

2. To improve the energy efficiency of the bus, an overall Intelligent Hierarchical and Hybrid Controller Strategy (IHHCS) is proposed which will result in decreased energy consumption. A comparison is drawn between the already existing frameworks and the proposed EMS based framework.

The observation of the proposed work includes the following:

- Battery longevity is enhanced by holding SOC within the range.
- Implementation in real-time environment
- Improved vehicle efficiency
- Reduced energy consumption
- Applicable in many types of hybrid vehicles.

The paper can be organised such that section 2 deals with the three-level execution of the proposed work with the help of three controllers at each level. Section 3 gives the experimental results of the work and a conclusion is drawn in section 4.

2. Proposed Methodology

The proposed research work has considered an intelligent hybrid vehicle model of a bus, which is embedded with IHHSC [27]. This will decrease total energy consumption and at the same time the efficiency of the vehicle has been improved. Three levels of controlled presidents are developed in the proposed work:

- To set points of HM and EM using Internal Combustion Engine (ICE) - Local fuzzy tuning proportional integral derivative (LFTPID) controller.

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- To split power and decide the optimal combination of power sharing - Intelligent power distribution and optimisation (IPDO) controller.
- To control the various operational modes of the bus - Intelligent supervisory switching mode (ISSM) controller.

2.1 ISSM Controller

There are 3 modes of operation in this controller to improve the functioning of HHEV. An appropriate mode or a combination of them are selected based on the parameters that require improvement such as power supplied by the battery, vehicle speed, vehicle power required value of SOC for battery etc. According to the position of the pedal, it is possible to accelerate or decelerate the vehicle. When the $T>0$, the energy is split between HM and EM through ICE and when $T<0$, torque regenerative braking mode is selected. Modes 1,2 and 3 are apt while using fuzzy logic as the boundary or range is not clear with respect to the vehicle's state of condition (velocity, mass, etc.). This controller uses operation mode as the output variable and SOC, T value and reference speed as the input variables. Here the input variables and the output variables are subject to Gaussian Membership Function (GMF) while the output fuzzy signal is subject to centre of gravity defuzzification [28].

2.2 IPDO Controller

In the second level, the IPDO controller is used which takes advantage of both ANN and Fuzzy systems. Fuzzy Management Controller (FMC) and Learning Adaptive Algorithm (LAA) are the two blocks involved. HM and/or EM will contribute towards providing the required torque using the FMC block. Similarly, the LAA block uses the output variables of FCM to operate on a neural network. The optimum, actual and total efficiency of the vehicle is determined using the elementary efficiency such as transmission, Hydraulic Pump (HP), Hydraulic Motor (HM), ICE, battery and Electric Motor (EM). An optimal implementation of this level will lead to generation of set points for the first level, tuning of optimal parameters

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depending on the ANN optimization, identifying the best combination of power distribution that will result in optimal efficiency of the hybrid vehicle. The primary objective is to make appropriate working points for EM and ICE that will positively improve the efficiency of the overall system.

The Fuzzy inferred output can be given as:

$$T_{EM} = \frac{\sum_{a=1}^{x} \sigma_{em,a1}\sigma_{em,a2}m_{em,a}}{\sum_{b=1}^{x} m_{em,a}\sigma_{em,a2}} \quad (1)$$

$$T_{ICE} = \frac{\sum_{b=1}^{x} \sigma_{ice,b1}\sigma_{ice,b2}m_{ice,b}}{\sum_{b=1}^{x} m_{ice,b}\sigma_{ice,b2}} \quad (2)$$

Where $\sigma_{em,a1}\sigma_{em,a2}$, $\sigma_{ice,b1}$and $\sigma_{ice,b2}$ represents the standard deviation of GMF for EM and ICE respectively while $m_{ice,b}$ and $m_{em,a}$ are the weights of bth and ath output membership function. The parameters can be further optimized if they are able to satisfy the conditions:

$$\sigma_{ab1}^{k+1} = \sigma_{ab1}^{k} - \tau^{c} \sum_{c=t+1}^{t+s} \sum_{b=1}^{N} (e_{ED}^{c}\mu_{TD,ab} + e_{EF}^{c}\mu_{EF,ab}) \quad (3)$$

$$\sigma_{ab2}^{k+1} = \sigma_{ab2}^{k} - \tau^{c} \sum_{c=t+1}^{t+s} \sum_{b=1}^{N} (e_{ED}^{c}\mu_{TD,ab} + e_{EF}^{c}\mu_{EF,ab}) \quad (4)$$

Where σ_{ab1} represents $\sigma_{ice,b1}$ and $\sigma_{em,b1}$ for (1) and (2) and σ_{ab2} denotes $\sigma_{ice,b2}$ and $\sigma_{em,b2}$ for (1) and (2) representing the standard deviation and mean of GMF. Here $e_{EF}$and e_{TD} represent efficiency of the vehicle and torque demand while $\mu_{EF,ab}$ and $\mu_{TD,ab}$ denote the weights of ath rule of bth training pattern. 't' represents the trailing edge of the changing window of time; c is the iteration index and τ^{c} is the learning rate.

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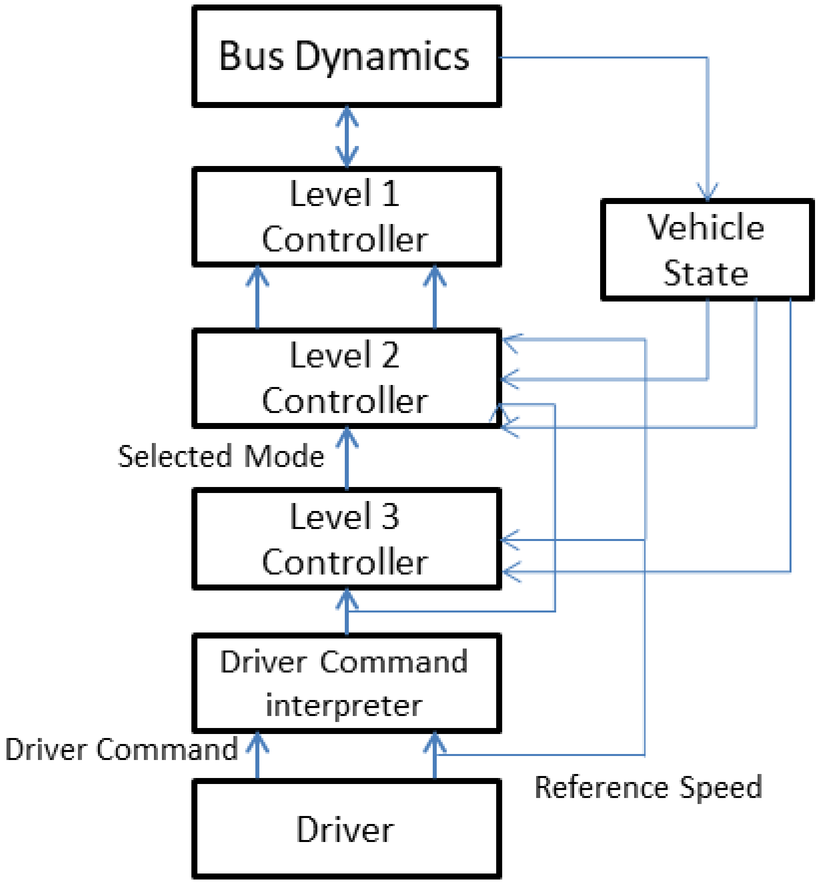

Figure1. Distributed Generation System following three levels of controllers

2.3 LFPID Controller

Based on the work of authors in [29] and [30], the HM and EM using ICE is designed in this work. Both level 2 and 3 are given higher focus in this part of the work. Here, fuzzy logic inference system is used in the adaptive PID controller to evaluate the parameters. A combination of fuzzy control algorithm and PID controller is used and it is observed that the LFPID controller performs better than other traditional methodologies.

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3. Results and Discussion

The total amount of energy consumed by the internal combustion engine for three methodologies namely StateFlow (SF), Optimal Fuzzy Logic Control (OFLC) and the proposed IHHCS are observed in the Fig.2. Similarly the total amount of energy consumed by the vehicle is also observed in Fig.3 using the above mentioned methodologies. The graph indicates an increase in the efficiency of the vehicle. For obtaining a specific comparative analysis, the total energy consumed and the variation of SOC is recorded in the Table 1 for the driving cycle where FEC denotes Fuel Energy consumption by the internal combustion engine.

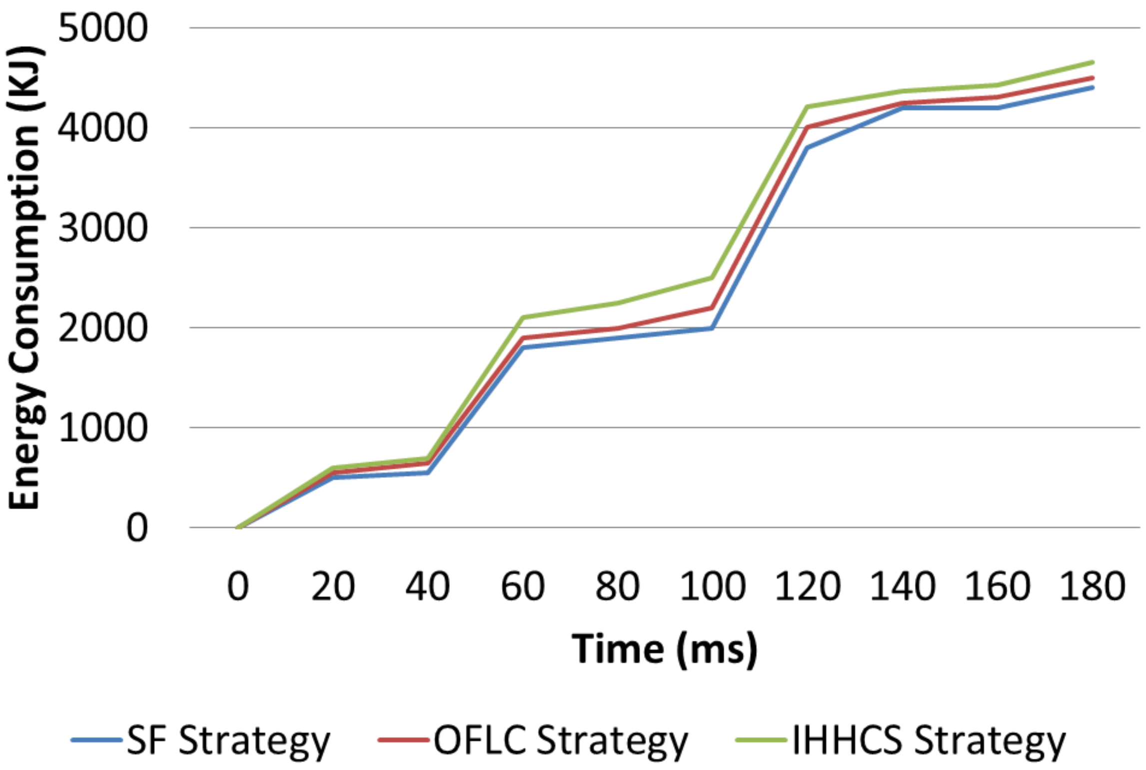

Figure 2. Total Energy Consumption by the Internal Combustion Engine

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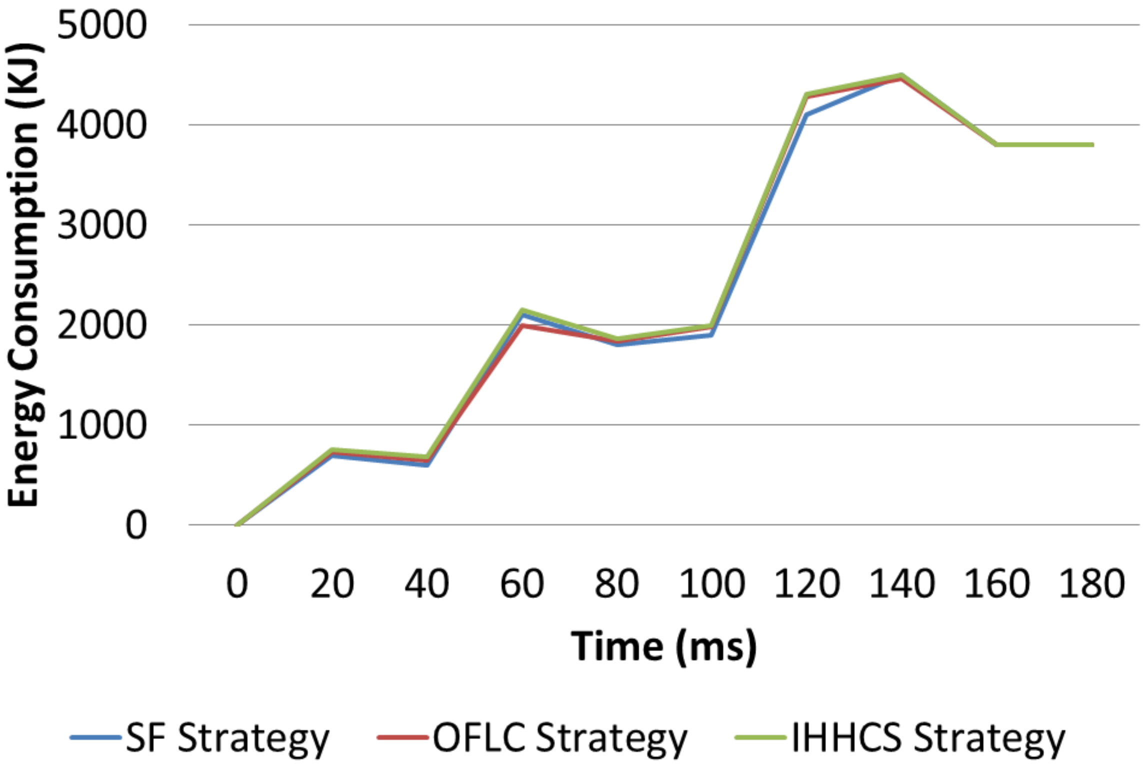

Figure 3. Total Energy Consumption by the Vehicle

Table I. Comparative Study of SF Strategy, OFLC Strategy and proposed IHHCS Strategy

Control Strategy	SOC	FEC by ICE
IHHCS	3500	96.1
OFLC	3600	96.03
SF	3650	96.96

4. Conclusion

There are two crucial aspects of optimization and control of HHV power management. The first section of this proposed methodology is designed towards the validation and development of the bus design with the help of TruckMaker. The ICE and battery are the two

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energy sources that are used in this proposal. The next section of the work deals with improving energy efficiency, decreasing the total energy consumption and results in positively improving distance covered between refuelling. A number of traditional and popular methods are studied in a comparative analysis with the proposed work. Three control levels are incorporated in the proposed work and uses intelligent hierarchical and hybrid control strategy for power management in real-time. Here a fuzzy system is used determining the apt mode of operation. The next level is the IPDO controller which is used for splitting power with neuro-fuzzy logic. The lowest level is LFPID controller that can set the points of HM and EM using the internal combustion engine.

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etc. He has membership in various professional bodies like ISTE, IAENG etc., and has actively involved himself in organizing various international and national level conferences, symposiums, seminars etc.

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