International Journal of Engineering Sciences 2022 15(1) 33 - 42

INTERNATIONAL JOURNAL
OF
ENGINEERING SCIENCES

Development of EMS for Hybrid Electric Two-Wheeler

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(Received 30 July 2021; Accepted 27 March 2022)

DOI: https://doi.org/10.36224/ijes.150105

Abstract
Rising the emission level from conventional vehicles (CV) is a major concern of today's world. Electric vehicle (EV) and hybrid electric vehicles (HEV) technology are two ways to deal with it. EV technology is an emerging technology but they have some challenges in adopting the EV technology. So, this paper deals with modelling and simulation of a hybrid electric vehicle such as series hybrid electric vehicle and parallel hybrid electric vehicle with different energy management strategies. The heart of HEV development is energy management strategy (EMS), on which vehicle's performance and fuel consumption can be optimized. For series HEV charge depleting charge sustaining (CDCS) EMS has been used and for parallel HEV rule-based (RB) EMS has been used. Supervisory control algorithms play important role to allow smooth power flow between the engine and electric source. There are different EMSs such as rule-based, optimization-based (OB), and learning-based (LB). These EMSs are used to split the power flow. In this paper, fuzzy logic controller (FLC) as an energy management strategy is proposed for a parallel hybrid electric vehicle, further this strategy is compared with RBEMS. The simulation results are compared and analyzed which shows there is improvement in range and reduction fuel consumption. In this study, MATLAB/Simulink and QSS toolbox are used for the simulation.

Keywords: Electric vehicle, hybrid electric vehicle, energy management strategy, rule based, optimisation based, learning based, fuzzy logic controller

Nomenclature:
CV: Conventional Vehicle
EV: Electric Vehicle
HEV: Hybrid Electric Vehicle
EMS: Energy Management Strategy
FLC: Fuzzy Logic Controller
FC: Fuel Consumption
EC: Energy Consumption
SOC: State Of Charge
QSS: Quasi Static Simulation

1. Introduction

Technological advances in the transportation sector increased the need for petroleum production, high gasoline prices, and climate change have arisen as a result of the increasing use of fossil fuel-based products. To address the aforementioned issue, hybrid electric vehicles and electric vehicles have recently been developing. Hybrid electric vehicles have two or more than two prime movers for propulsion and at least one of them should be an electric motor. As per, HEV concern we are using an electric source with ICE so there should supervisory control is needed to propel the vehicle. For that reason, Energy Management Strategy (EMS) came into a concept. To efficiently split power flow, EMSs

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ISSN 0976 – 6693.

will be important in the development of HEVs. An EMS's primary goal is to split supply power by taking into account the best multi-motive source to fulfil driving demand [1].

Concerns over the limited supply of fossil fuels have prompted a surge of research inthe study for alternate road transportation technologies in the market that as HEVs and EVs. Moreover, governmental efforts to lower urban pollution, CO2 emissions, and city noise have made hybrid electric vehicles an appealing option to combustion engines. In recent years, the transportation sector has emerged, with policymakers playing a key role in a state to transform this sector. Most of the usage of this sector comes from fossil fuel-based vehicles, according to the Energy Information Administration. Transportation is also the biggest source of greenhouse gas emissions (GHGs) in the United States, accounting for 28% of total emissions. For the development of an energy management strategy, we use a fuzzy-enabled control strategy that will take care of the nonlinear behaviour of the vehicle and easy to manipulate fuzzy rules. In a rule-based energy management strategy, we use programmable logic for the development of EMS, which will not take care of the nonlinear behaviour of a vehicle.

2. Architecture/topology of hybrid electric vehicle

There are three main power train architectures of hybrid electric vehicles. For the development of EMS, it is important to understand different modes of operations of power train topology. A power train modelling approach and its complexity to develop EMS is significant to split the power flow between the engine and electric machine.

2.1 Series hybrid electric vehicle

In a series-HEV (S-HEV) architecture ICE who drives generator convert mechanical power into electric power through power electronics of generator and that power is supplied to electric motor and feed to wheels. Because the ICE is isolated from the wheels, it can function at peak efficiency by adjusting the ICE speed in response to load profiles. S-HEV topologies are largely being explored for buses and urban vehicles to achieve excellent performance in stop-and-go driving, but they are not appropriate for highway or inter-urban transportation due to greater conversion losses and the requirement for a large EM at high speeds [2].

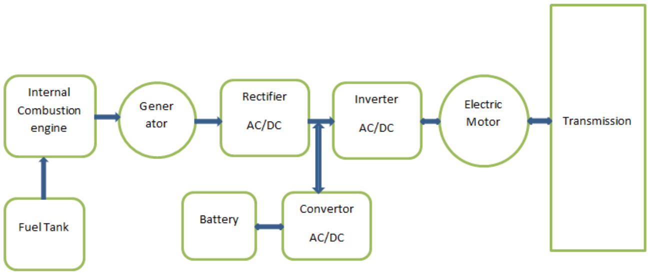

Figure 1: Series Hybrid electric vehicle topology

2.2 Parallel hybrid electric vehicle

Parallel hybrids are versions in which the engine and the electric motor, either independently or jointly, generate traction power. In this configuration, the electric motor may be operated as a generator to charge the battery, either by regenerative braking (energy recuperation) or by being driven directly by the engine. A clutching mechanism that divides the drive based on demands is necessary since the (ICE) is mechanically coupled to the drive train. This allows them to individually change their torque. The engine and the electric motor's speeds cannot be changed independently since they are coupled by a torque coupler (TC) with a fixed ratio. The engines torques and the electric motor torque is coupled using torque coupler [3].

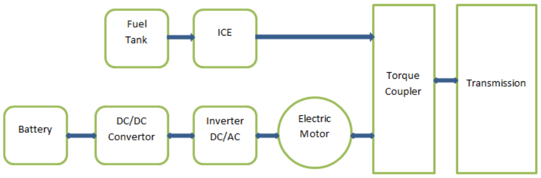

Figure 2: Parallel Hybrid electric vehicle topology

2.3 Series-parallel hybrid electric vehicle

The hybrid design that is partly between series and parallel is known as mixed hybridarchitecture. The electric motor is employed as a generator for regenerative braking, much like in parallel hybrid arrangements. In a series hybrid system, the electric generator is employed to charge the battery via the engine or for start/stop operation. The ICE and EM are coupled through mechanical torque coupler device [4].

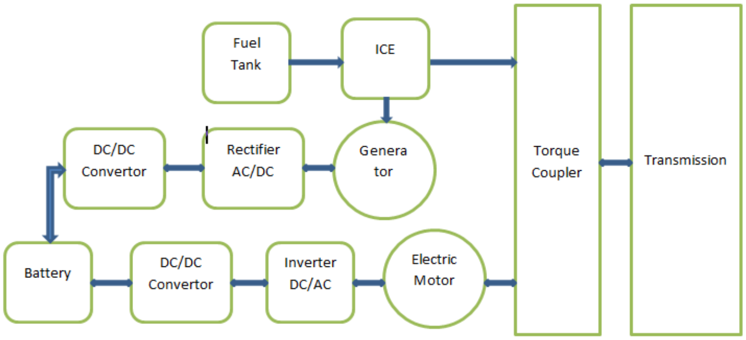

Figure 3: Series-parallel hybrid electric vehicle

3. Energy Management Strategy

Based on a requested torque, the energy management control strategy determines thepower distribution between the internal combustion engine, electric motor, and electricgenerator. The major goal is to improve fuel efficiency while maintaining within the constraints imposed by drivability standards and component characteristics. Rule-based and optimizationbased techniques are the mainly two types of energy management control systems. However, there are many supervisory control algorithms. The following is a classification of various EMS:

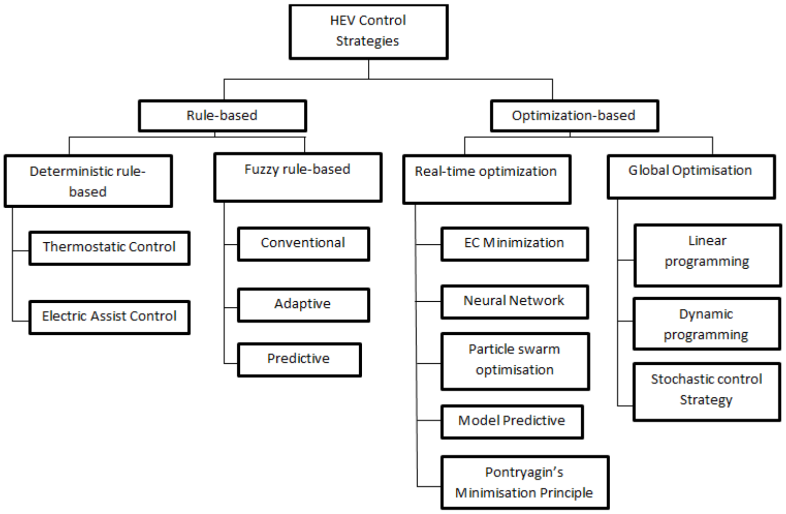

Figure 4: Classification of EMS

3.1 Rule based EMS

Without previous experience of the driving cycle, rule-based EMS depends on heuristicsor technology skills. The key advantage of this EMS is its ease of use and ability to be implemented in real time in a vehicle. We can easily tune the parameters using this EMS.

However, there is some limitation while applying rule-based EMS is that optimality. There is also significant effort is required for calibration so that fuel consumption and emission are reduced. The setting rules are not up to the mark as required for different power train topologies and component sizes. This EMS can develop having prior knowledge of different modes of power flow between ICE and EM. There is also a use different optimization strategy with rule based so that our objective is obtained. Such a strategy includes a multi-mode strategy combined with ECMS [7], a thermostat combined with driving recognition [8]. The deterministic and fuzzy-logic EMSs are two types of rule-based EMS.

A fuzzy logic method reduces human cognition and perspective to a set of IF-THE Nrules. Initial quantization, fuzziness, the reasoning of fuzzy, fuzzy inverse, and output quantization are the five steps of this technique. In fuzzy logic control strategies, which are determines with the help of membership functions and fuzzy rules at the fuzzy reasoning stage.

The main advantage of this strategy is that the rules can be easily tuned and its robustness owing to its independence from mathematical model of controlled system and its adaptation. This enables fuzzy logic strategy to handle multi domain, time-varying, and non-linear problems which are found in the EMS of vehicle system. For example, Baumann et al. [9] and Salman et al. [10] developed fuzzy logic control to coordinate the operation of parallel HEV subsystems. To overcome non linearity FLC has more advantage.

3.2 Optimization based EMS

The objective of an optimization-based control approach is for the controller to reduce the cost function in order to achieve optimal results. The cost function or objective function depends upon developer that he has to consider as fuel consumption, range improvement and also control of emission levels. This strategy is very complex in nature, time consuming and it is not easily implemented in vehicle. The cost associated with this strategy is also expensive so you have to consider this thing also while development of EMS. The objective of optimization based (OB) EMS is to find the optimal control sequence that minimize a cost function while meeting the dynamic state constraints example battery SOC local state constraints such as power limit, speed limit and torque limits. As in this work we are not using OB strategy in our vehicle so we not go in depth.

4. Proposed EMS

In the proposed energy management strategy we use the charge depleting charge sustaining (CDCS) strategy for S-HEV and rule-based and fuzzy logic controller strategy for PHEV. For simulation purposes, we take 2W as our vehicle. The vehicle specification of 2W is shown in table 1. The main objective is to improve fuel consumption and range. In the simulation, we did a simulation of CV, EV, S-HEV, and P-HEV using MATLAB/Simulink QSS toolbox.

4.1 CDCS EMS

CDCS EMS strategy is used for S-HEV. In S-HEV electric motor is only responsible for the propulsion of a vehicle. For the development of S-HEV, we are using a rule-based charge depleting charge sustaining (CDCS) energy management strategy. In this EMS we are taking battery state of charge as the main parameter to develop. As in the simulation we are using basically two electric machines (EM) one acts as an electric motor and the other as an electric generator. In a series hybrid electric vehicle, there is no need to use two electric machines, as we use two because we have to increase the range. The main purpose to use an electric generator is to reduce the battery power and increase the range and decrease fuel consumption. We define two limits for battery state of charge as maximum and minimum limits. If the battery state of charge is below the minimum value the then the vehicle is in charge sustaining mode and if the battery state of charge is maximum then it will be in charge depleting mode.

4.2 Rule Based EMS using MATLAB script

Rule-based energy management strategy is the heuristic approach which typically depends upon the history of the vehicle's behavior and human experience. As in rule-based EMS, we are going to develop logic according to different modes of the hybrid electric vehicle.In regeneration mode as the brake, energy is going too lost in wheels so we are utilizing this energy to charge the battery through an electric motor when the torque is negative on the wheel. In battery-only mode, the internal combustion engine is kept off as a state of charge in start initially. When battery SOC is less than a certain predefined value and required torque is that much not high we are utilizing it to turn on the internal combustion engine. When we enough battery SOC and the required torque is too high then the vehicle is propelled by bothICE and EM. Different modes of HEV and required logic can be developed using the ref. [6].

4.3 Fuzzy Logic Control strategy

In this application, FLC is used to execute energy management in a P-HEV. VariousHEV characteristics, such as torque availability and SOC, are used as input variables to theFLC controller. Requested Torque and SOC are categorized into four membership functions (MF), which are very low, low, medium, high, and very high. The controller will provide two outputs an internal combustion engine and an electric motor. As in internal combustion engine, we use two membership functions as ON/OFF (1 or 0) and for an electric motor, we use three membership functions as ON-OFF and ABSORB that is (1 0 -1). The input and output of MFs are shown below with their simulation. When the generator is in ON condition, it means that the battery is getting charged using ICE. If ICE is OFF and the battery is still getting charged, it can happen due to braking energy where the motor acts as a generator to charge the battery.

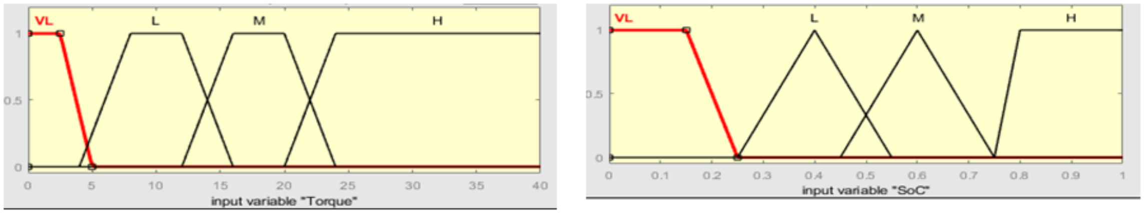

Figure 5: Input MF for toque demand and battery SOC

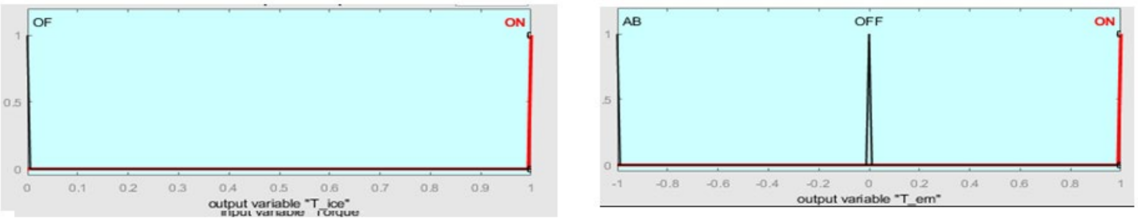

Figure 6: Output MF for torque of ICE and EM

Table 1 Vehicle Parameters of 2W

Total mass of vehicle	300 kg
Rotating mass	2 %
Cross sectional area	0.8 m^2
Wheel diameter	0.4318 m
Drag coefficient	0.7
Rolling friction coefficient	0.015
Fuel	Gasoline
Fuel density	0.745 kg/l
Maximum Power of ICE	15.48 KW
Maximum Torque of ICE	19.12 Nm
Maximum Power of EM	3 KW
Maximum Torque of EM	170 Nm
Transmission System	5 speed manual 2.769,1.882,1.380,1.082,0.88,2.571
Type of Cell	Li-ion
Voltage of Cell	3.8 V
Polarization Voltage	0.00876 V
Cell internal resistance	0.09 Ω
Capacity Of Cell	15 Ah

5. Simulation Results

We used MATLAB/Simulink QSS toolbox as an environment for simulation of CV, EV,S-HEV, and P-HEV. For simulation of these vehicles, there are two modeling approaches which are forward-based and backward-based. We used a backward-based modeling approach for the development of the hybrid electric vehicle. In the backward modeling approach, we go from wheels to the energy source. It is a non-casual model because the calculation process starts from the wheels to the engine/electric motor.

Driving cycle models which gives input to vehicle model. In QSS time is broken down into the finite amount of time steps h, in each of this time step system is interpreted as a static system. In QSS look-up tables and charts are used. QSS toolbox provides a fast and simple estimation of fuel consumption. From the simulation, we get different graphs such as fuel consumption (lit/100 Km),battery SOC (%), the power output of internal combustion engine, and electric motor. The results of P-HEV using rule-based and FLC strategy are shown in below Figure 7 and Figure 8.

We are using the NEDC cycle for the 2W application. As in Figure 8, we show only a single graph for both the proposed strategy of torque from manual gearbox (MGB), as the torque demand is the same as MGB. For validation of developed EMS, we are using [5]. In this literature we use a 4W vehicle for validation because for 2W applications there are not much work is done for HEVs. In this literature fuzzy enabled logic is utilized to split the power flow between the engine and motor using the FTP-75 drive cycle. This literature deals with hardware in loop validation using an FPGA-based Micro lab box Hardware controller. The results much promising which is shown in different graphs such as fuel consumption, battery state of charge, the power output of ICE and EM shown in Figure 9,10.

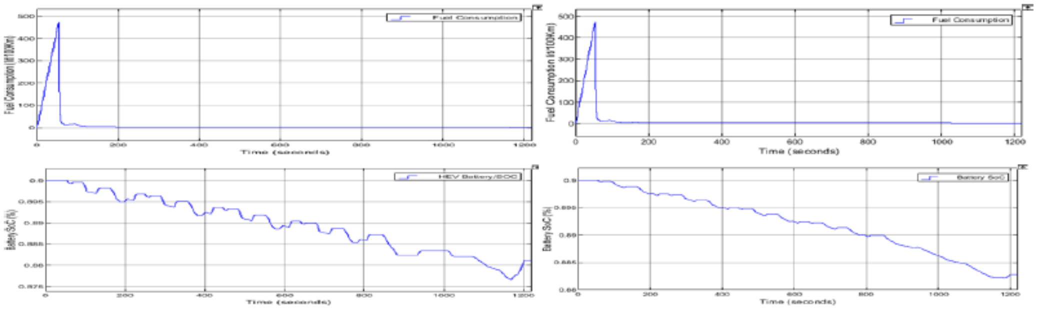

Figure 7: FC and Battery SOC of 2W using RB and FLC strategy (NEDC)

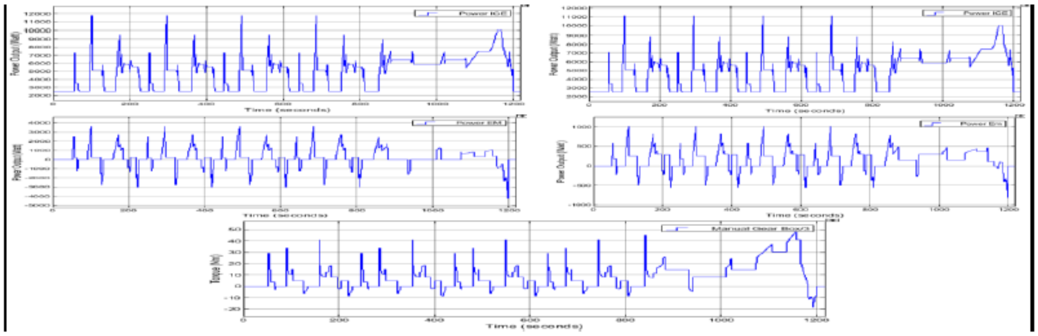

Figure 8: Power output of ICE and EM, Torque demand from MGB using RB and FLC strategy (NEDC)

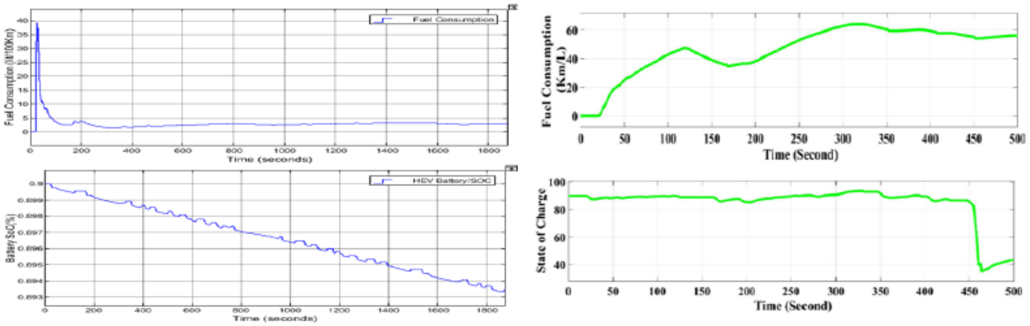

Figure 9: FC and Battery SOC validation of 4W using FLC strategy (FTP-75)

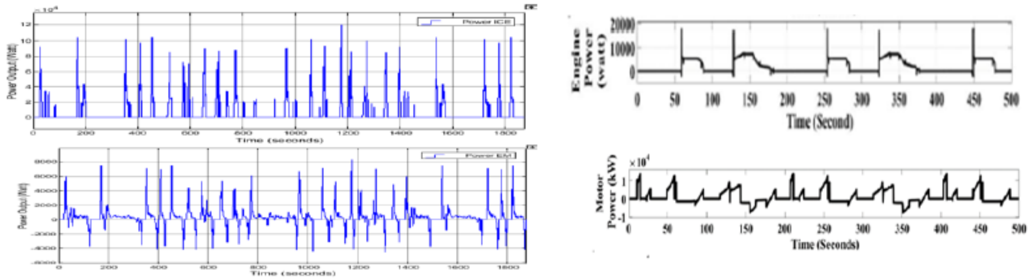

Figure 10: ICE and EM power output validation of 4W using FLC strategy (FTP-75)

In table 2 you can see hybrid electric vehicles shows less fuel consumption and anincrease in range of the hybrid electric vehicle. As in a series hybrid electric vehicle, you see some more amount of fuel reduction, because we use an extra electric machine which works as a generator and supplies the energy wherever required. So, it acts as a range extender. In passenger vehicles, we can easily utilize more than one electric machine as there is no space constraint but in 2W it is a bit difficult to use two electric machines. As in table 2, you see SHEV has well improvement in fuel consumption as that of P-HEV using proposed EMS. In table 3 parallel FLC strategies gives better results as compared to that of RB EMS.

Table 2 2W vehicle results using NEDC

	Conventional Vehicle	**Electric Vehicle**	**Series HEV (CDCS)**	**Parallel HEV (RB)**	**Parallel HEV (FLC)**
FC (Km/lit)	46.06	NA (16.22km)	78.74	51.68	52.08

Table 3 Comparison in fuel consumption with different HEVs

Comparison in fuel consumption (%)	**2W vehicle (NEDC)**
Parallel FLC with CV	13.07 %
Parallel RB with CV	12.20 %
Parallel FLC with parallel RB EMS	0.77 %
Series HEV with CV	70.91%

Table 3 shows comparison of parallel HEV with conventional vehicle, parallel FLC gives better results as compared to parallel RB strategy which is 0.77%.

6. Conclusion

Throughout the paper, we can infer that the importance of HEVs and EVs in today's world. The design aspects of power train and energy management strategy for the hybrid electric vehicles have more attention now a day. As we simulate conventional vehicles, electric vehicles and series, and parallel hybrid electric vehicles. For series hybrid electric vehicle fuel consumption reduces greater as compared to a parallel hybrid electric vehicle because we use two electric machines in the series hybrid electric vehicle which range extender. But, due to space constraints, it is not easy to install two electric motors in the 2W application. We utilize a fuzzy logic controller in a parallel hybrid electric vehicle with two input membership functions and two output membership functions which shows some improvement in fuel consumption as that of rule-based energy management strategy.

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