Examination on Classification of EVs and Energy Management Strategies of HEV

Karkuzhali S, Usha Rani P

Abstract: ***In recent days, the demand for petroleum and emission of pollutant gases continuously increase. This necessitates the electrification power train which replaces Internal Combustion Engine (ICE). Despite pure electric vehicles or Battery Electric Vehicle (EV) reduce the greenhouse gas emissions, there are some major hurdles for EVs to overcome before they totally relieve ICE vehicles form transport sector such as range anxiety, battery storage, economic fall down due to automobile industries, etc. This necessitates Hybrid Electric vehicle (HEV) which combines two different power sources to propel the vehicle. One of the challenges in HEV is how to control the power coming from the two different sources such as battery and ICE. The prime goal of an Energy Management Strategy (EMS) is to manage energy flow such that fuel consumption and emissions are minimized without affecting the vehicle's performance. In this paper, the different structures of power train and energy management strategies are analysed.***

Keywords: ***Hybrid Electric Vehicle (HEV), Energy Management Strategy (EMS), State of Charge (SOC).***

I. INTRODUCTION

Now a days, due to increase in demand for non-renewable fuel which are finite source, there is an increase in fuel price. Burning of fossil fuels, particularly for the power and transportation sectors are most responsible for air pollution, legislations in most of the countries are pushing for lower emissions. This necessitates electrification of power train in automobiles. But it is not possible to entirely electrify automobiles which will lead to economic fall down in the automobile industries and practical constraints such as long driving range and quick refuelling expected by consumer calls for hybrid electric vehicle (HEV).This paper is presented to provide an outline about the recent progress on electric vehicles and various energy management strategies which plays major role to lessen the fuel emission and to provide optimal power split between battery and fuel engine without compromising in vehicle's performance in HEV. This paper is organized as follows section II deals with classification of electric vehicles. Section III focuses on different architectures of HEV and Section IV deals with existing energy management strategies for HEV and plug-in hybrid electric vehicle (PHEV).Section V presents comparison of fuel consumption using various EMS.

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II. CLASSIFICATION OF ELECTRIC VEHICLES

According to the trade off between the customer satisfaction in terms of long range drivability and less emissions forced by government legislations, there can be different types of electric vehicles such as

- Battery Electric Vehicle (BEV)
- Hybrid Electric Vehicle (HEV)
- Fuel Cell Electric Vehicle (FCEV)
- Plug in Hybrid Electric Vehicle (PHEV)

DIFFERENT ARCHTECTURES OF HEV

Vehicles which are powered by at least two sources, usually combining an internal combustion engine (ICE) and an electric motor (EM) is referred as Hybrid Electric Vehicle (HEV) [3]. Based on this, architectures of HEVs are classified as

1. Series HEV
2. Parallel HEV
3. Series–parallel HEV
4. Complex HEV

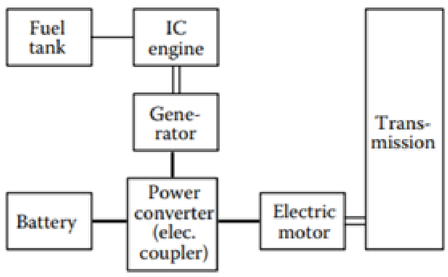

Fig.1. Series HEV [4]

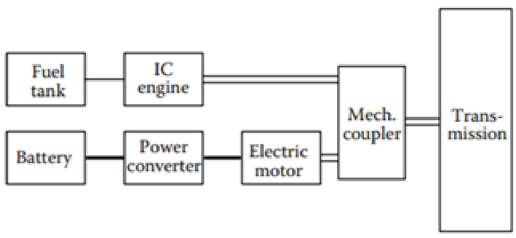

Fig.2. Parallel HEV [4]

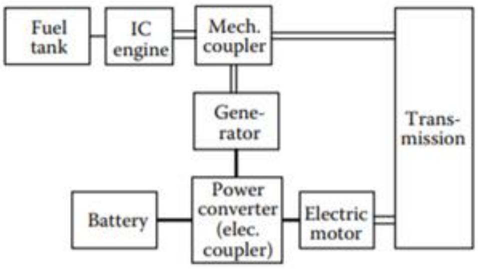

Fig.3. Series-parallel HEV [4]

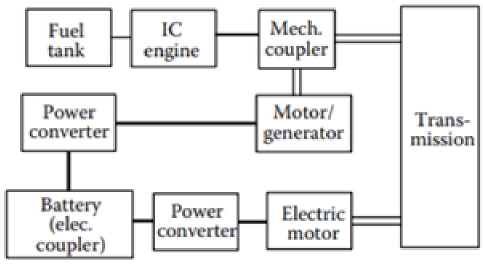

Fig.4. Complex HEV [4]

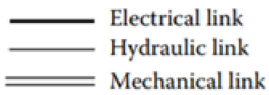

Table –I: Comparison of different types of electric vehicles. Data obtained from [1-2].

Type of EV	Driving Component	Energy Source	Features	Challenges
BEV	1.Electric motor	1.Battery 2.Ultracapacitor	1.No emission 2.Not dependent on oil 3.Type of the battery decides range. 4.Available commercially	1.Cost and capacity of the battery 2.Range 3.Time required to charge. 4.Availability of charging stations 5.High price
HEV	1.Electric motor 2.ICE	1.Battery 2.Ultracapacitor 3.ICE	1.Very little emission 2. Long range 3.Power obtained from both electric supply and fuel 4 Presence of both electrical and mechanical drive trains made complex structure. 5.Available commercially	1.Management of the energy sources 2.Battery and engine size optimization
FCEV	1.Electric motor	1.Battery 2.Fuel cell	1.Very little or no emission 2. High efficiency 3.Not dependent on supply of electricity 4.High price 5. Available commercially	1.Cost of fuel cell 2.Availability of fuelling facilities
PHEV	1.Electric motor 2.ICE	As battery can be recharged directly from the grid, multiple power sources can be used 1.Battery 2.ICE	1.Very little emission 2.Long range 3 power from both electric supply and fuel. 4.More degrees of freedom to supply the power demand	1.Management of the energy sources 2.Battery and engine size optimization

Table –II : Comparison of different architectures of HEV: [4]

Sl.No	Type	Coupling used	Features
1	Series HEV	Electrical Coupling	Two electric powers are added.
2	Parallel HEV	Mechanical Coupling	Power from electric motor and ICE are added together in a mechanical coupler.

3	Series–parallel HEV	Mechanical And Electrical Coupling	It combines the features of series and parallel hybrid. It has more operating modes.
4	Complex HEV	Mechanical And Electrical Coupling	It accommodates two power converter and one mechanical coupler. It has complicated structure and high cost.

III. EXISTING EMS FOR HEVAND PHEV

Based on the literature survey, energy management strategies are grouped in three categories such as in [22].

- Rule Based EMS
- Optimization Based EMS
- Learning-Based EMS

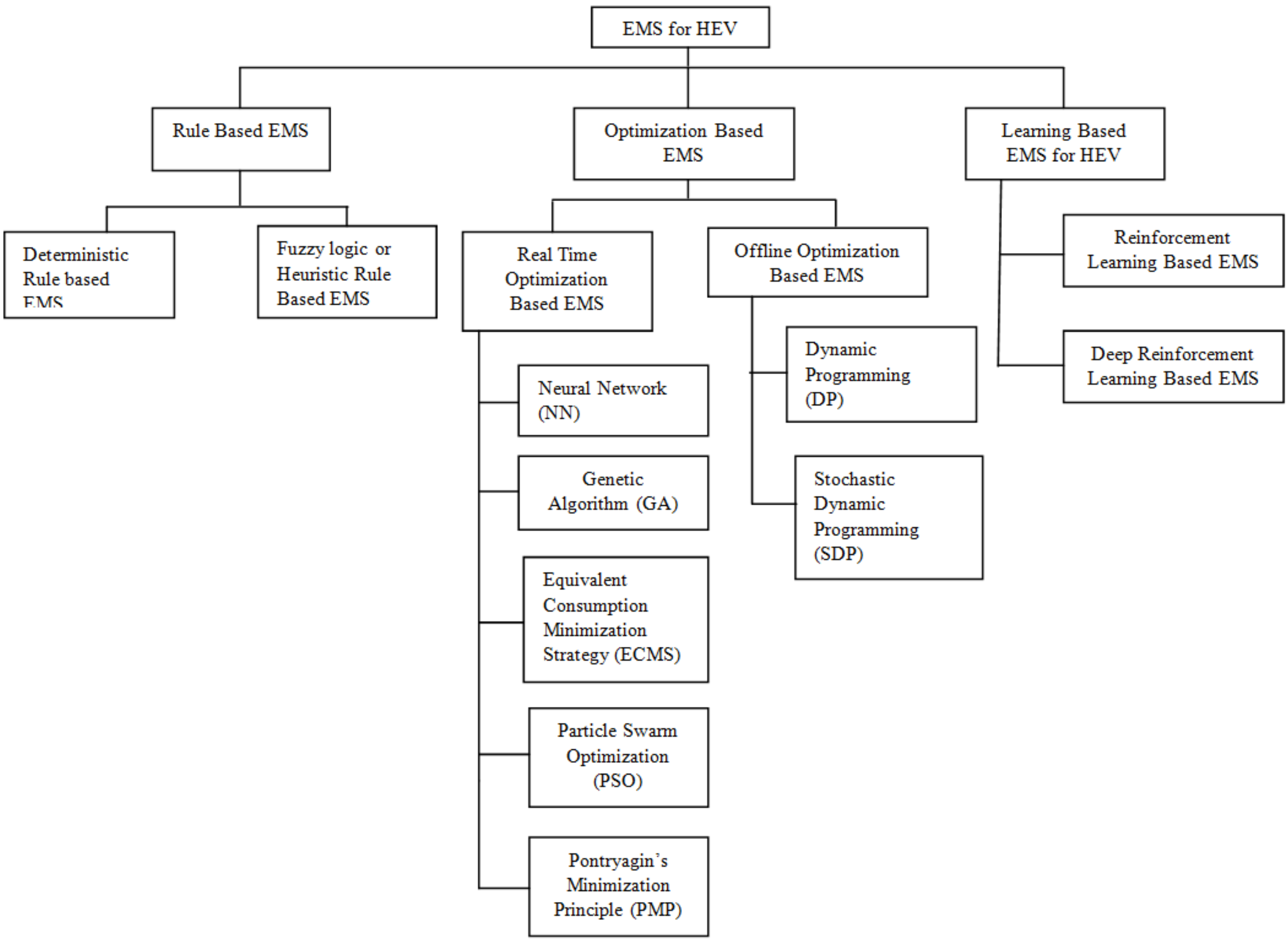

Fig.5. Different types of existing energy management strategies

A. Rule-based EMS

Rules are initially formed based on the assumption of future driving conditions and on desired outputs. And these rules can be deterministic rule-based and fuzzy logic rule-based [5].

- **Deterministic Rule-Based Methods**

Nashat Jalil et al. developed rule based EMS for series HEV [5].The researchers used thermostat and rule based energy management strategy. In thermostat, the status of SOC of battery is used to turn on the engine. In rule based power split, considering thermostat background and acceleration command ,power will be supplied by fuel engine or battery or combination of both.

Liu Shaohua et al. introduced rule based energy management strategy for Belt Driven Starter Generator in which all possible road load conditions are included to form rules for energy management strategy [6]. Harpreetsingh Banvait et al. proposed energy management strategy for plug in hybrid electric vehicle (PHEV) [7]. In all these rule based method, rules are clearly defined for power split by battery and Fuel engine but these methods fail to work under situations faced by vehicles non linear driving conditions.

- **Fuzzy logic or Heuristic Rule based EMS**

Fuzzy logic controllers are rule-based systems which use linguistic variables and simple rules to imitate the human reasoning process. As fuzzy rule-based approach does not require precise mathematical models of the controlled system, they are particularly useful when applied to complex multi-domain system nonlinear, time-varying systems like HEV [9].

The researchers presented fuzzy logic control of EMS for parallel HEV [8],[10]. Here fuzzy membership function is assigned for SOC of battery and the difference between the torque required by vehicle and the torque provided by engine. The disadvantage of these methods is the requirement of expert knowledge which must involve in the process of fuzzification and defuzzification used for decision making.

B. Optimization Based EMS

Various optimization based EMS have been studied in this paper for energy management strategies in HEV [12]-[20].

Using maximum power search algorithm, engine operating points based on efficiency map of engine and generator, efficiency of battery is found out. This ensures optimal energy delivered by hybrid sources to drive system. But the overall engine efficiency is 1-2% less than equivalent consumption minimization strategy (ECMS) [12].

Some of the vehicles like city bus follow same driving cycle, the optimization method using deterministic dynamic programming (DDP) approach can be used to obtain global optimal solutions. Optimization algorithm based on the knowledge of the efficiency maps of the internal combustion engine (ICE) and the generator for the energy management system in hybrid electric vehicles requires a full knowledge of the driving cycle condition and is not suitable for real time applications due to its computational intensity [13].

Some of the intelligent management systems such as neural networks, fuzzy logic, Genetic algorithm and Particle Swarm Optimization are combined with global optimization methods to provide real time solutions for energy ratio split between battery and engine[14],[15].

Shaobo Xie et al. developed an Adaptive Equivalent Consumption Minimum (A-ECMS) Strategy for a Plug-in Hybrid Electric vehicle. But this method is proposed for only fixed route [16].These optimization methods do not offer an on-line solution and also the assumptions made here is the future driving cycle is known.

C. Learning-based EMS

Previously discussed EMS strategies are just follow predefined rules or assumption of future driving conditions which are not adaptive to dynamic driving conditions. In this study, a reinforcement learning based HEV energy management system is reviewed to autonomously learn the optimal fuel use from its own historical driving record. It does not rely on any prediction or predefined rules. Different learning based energy management strategies that are existing are discussed in this paper [21]-[26].

- Reinforcement Learning
- Deep Reinforcement Learning

Teng Liu et al. proposed two reinforcement learning namely *Q*-learning and *Dyna* algorithms. The fuel consumption is same and the computational cost is less than the dynamic programming [21].

The model proposed by Xuewei Qi et al. combines a Q-learning, a value based learning algorithm and a deep neural network to form a deep Q-network which is capable of learning and providing the optimal solution in continuous environment [22]. RuiXionga et al used the RL-based online strategy to reduce total energy loss due to temperatures, states of health, initial SOCs and driving cycles and improve the system efficiency under different conditions [23].

Deep neural network with Q learning proposed by Jingda Wu et al. in which the fuel economy of proposed DQL-based strategy gets a 5.6% better performance than Q learning [24].

IV. COMPARISON OF EMSs IN TERMS OF FUEL CONSUMPTION

Based on the analysis , among all energy management strategies, learning based EMS are preferred over rule based and optimization based EMS [25],[27].Driving range and SOC offered by learning Based EMS is also more [25],[28].Fuel consumption for various energy management strategies is listed in Table-III and the same shown in Fig.6. From Table-III, fuel consumption decreases by 8.3% using Rule Based EMS and 10.1% using Learning Based EMS.SOC profile for Rule Based, Charge Depleting-Charge Sustaining (CD-CS) mode, Optimization Based is shown in Fig.7.

Table –III: Comparison of different EMSs in terms of fuel consumption

Sl.No	Energy Management Strategy (EMS)	Fuel Consumption (L/100 km)
1.	Rule-Based EMS	3.857
2.	Optimization Based EMS (Dynamic programming)	3.537
3.	Learning-Based EMS (Deep Reinforcement Learning Based)	3.468

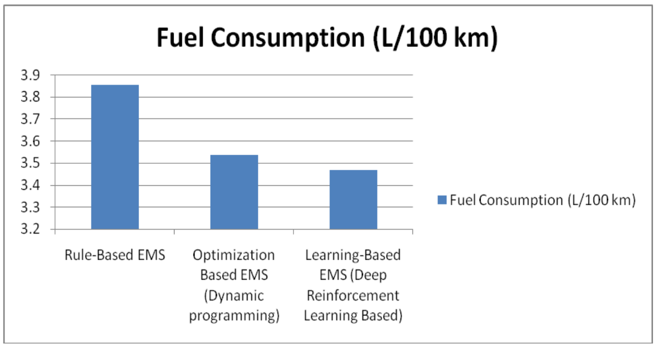

Fig.6. Fuel consumption using various EMS

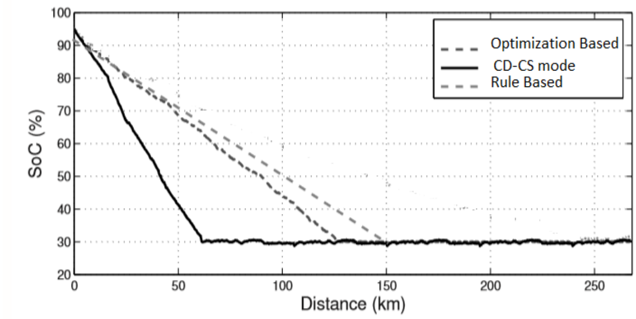

Fig.7. SOC profile

V. CONCLUSION

This paper focuses on analysis on classification of electric vehicles and different energy management strategies. Among different types of electric vehicles, due to long range drivability and lower emission, PHEV is preferred. This also provides room for vehicle to grid and vehicle to home power transfer. Based on the analysis on various existing energy management strategies for HEV and PHEV, Learning Based EMS is preferred. Still to get better vehicle performance, combination of EMS can be carried out as the driving cycles are not predictable.

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