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A Critical Review of Hybrid Electric Vehicles

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ABSTRACT

As per the growing consumptions of fossil fuels and its significant harmful impact on the environment, the fuel-efficient vehicle is highly preferable and thus its development is greatly accelerated. Hybrid Electric Vehicles (HEVs) have proven to be a better choice. Along with the better fuel efficiency, reduced emissions in compliance with the environmental laws, it lessens the crucial impact of rising gasoline prices on consumers. The HEVs include the electrical and internal combustion engine propulsion system. This work discusses a thorough analysis of the HEV components including the architecture, and the mathematical model and their Technology.

1. Introduction

The popularity of electric vehicles boosted the significance of research done in this area. The advancements in inverter/converter and battery technology have mostly improved the efficiency and range of EVs [1, 2]. Important research is also being done on the charging methods for EVs. According to those research, the rapid charging stations made specifically for electric vehicles put an excessive strain on the grid. There are also some other studies on the relationship between EVs and the grid [3–7] in which EVs serve as both a supply of electricity for the grid and a load. To enhance EV usage and consumer comfort, the authors suggest installing level 3 chargers in parking lots for businesses and retail establishments [8]. Direct current (DC), on the other hand, is used in level 3 charging mode to provide quick charging with high power capacity. Therefore, DC fast charging harms the grid and results in voltage quality issues. Fast charging-related peak demand poses problems with voltage stability, power quality, transformer losses, and grid operation lifespan [9–10]. It is suggested that the energy storage system (ESS) lower the cost of charging electric vehicles and buses [11, 12]. ESS can assist in lowering peak costs or low-utilization loads and lessening demand charges. There are

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other solutions to FCS problems as well. One of them proposes a hybrid charge station structure that is powered by photovoltaic (PV) solar panels for DC rapid charging [13]. Another study [14] analyses the solar panel and grid-supplied electrical charging station systems while taking into account the weather in the Netherlands. The fast charging system's sizing analysis for Ref. [15] compares battery sizes based on the system's renewable energy sources' power rates [16].

Nowadays, Electric Vehicles are getting attention and popularity due its several advantageous features. The most special quality of the EVs is the major contribution in the reduction of Greenhouse Gases emissions. In 2020, the transportation sector is responsible for the emission of more than 27% of Green House Gases [17]. EVs with its advance research and multiple analyses engineers are in the stages of reducing this huge figure of carbon emission. Being good as vehicle, with no fuel cost associated with conventional vehicle and easy operation, it is highly useful in the urban transport mode [18].

Conventional vehicles run on the principle of Internal Combustion Engine which runs on fossils fuels deposited under Earth more than thousands of years. As per the study more than 1.4 billion vehicles are in use in the world and about 296 million vehicles run on the roads and streets of India as per the research expert which was published by Shangliao Sun. Crude oil, or petroleum, is a naturally occurring liquid mineral that is the main source of motor vehicle fuel [19].

Table1
Average crude oil consumption per Day by country in 2020

Sr. No.	Country	Barrels Per Day
1.	United States	1,96,90,000
2.	China	1,17,50,000
3.	India	44,89,000
4.	Japan	40,26,000
5.	Russia	35,94,000
6.	Saudi Arabia	32,37,000
7.	Brazil	30,18,000
8.	South Korea	26,30,000
9.	Germany	24,10,000
10.	Canada	23,79,000

The table 1 above shows the top 10 countries' crude oil consumption in Barrels per day. United States (US) being the heighest consuming country while the India falls in the third largest crude oil cousuming nation after China. With the advancement in Urbanization, Industrialization, and Globalization, the number of vehicles increasing day by day, hence the transportation relies heavily on oil. Thus, the rapid growth of Global Automotive Market has immensely increased the need and demand for energy in the form of fossil fuels. ICE vehicles result in the production of carbon dioxide, hydrocarbon, sulphur oxides, carbon monoxide that is contributing to the Global Warming and harmful to both environment and lives. The conventional vehicle model isn't sustainable for the long run as the Earth has limited resources of fossils fuels and also the oil prices continue to sky the rocket. Considering these factors and its consequences on environment we need of developing an "Eco-Car" with good fuel economy and low carbon dioxide emissions [20].

A HEV consists of a conventional ICE propulsion system and an electric propulsion system [21]. In the technical tongue HEV can be defined as the technology indulges mechanical drive train and EV. This mechanical drive includes fuel tank, combustion engine, gear box, and transmission connected to the wheel as shown in the figure 1.

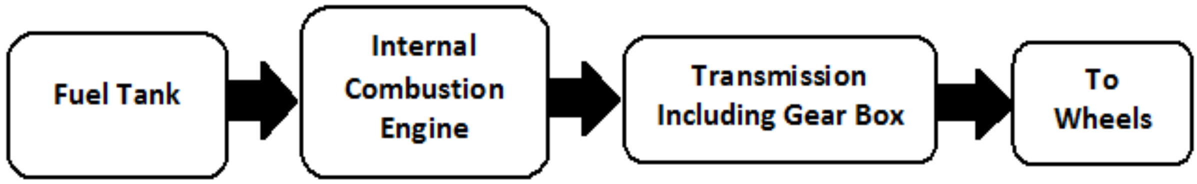

Fig. 1. Flow of energy within mechanical drive train [22]

Also, an electric drive comprises of the battery, an electric motor, and the power electronics for various controls, and the same is shown in figure 2.

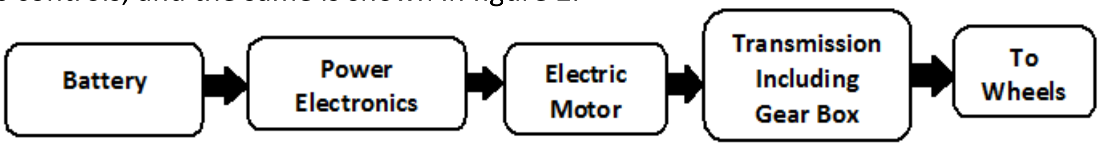

Fig. 2. Flow of energy within an electric drive train [22]

HEVs do not need external charging as it incorporates two energy sources engine and electric motor and thus special infrastructure is not required to use them. There are majorly three types of hybrid system stated such as series hybrid system, parallel hybrid system and series parallel hybrid system.

The addition of electric power train is deployed with the intention of achieving either better performance or better fuel economy than the conventional form of vehicles. Moreover, HEVs includes a greater number of electrical components namely batteries, power electronics converters, motors, sensors, etc. Especially the challenges which are encountered are the vehicles parameter optimization, proper range selection, and fuel economy up to an extent. The HEV deals with the lower exhaust emissions and better fuel economy as two sources of energy is used mainly the fuel, and the stored electrical energy [31]. In order to achieve best benefits, multiple configurations on different parameters are to be considered. In the stage of design and optimization it is important to the check with the extensive simulations with different power train configurations and components. Scalability enables the benefits in the design and optimization aspects in terms of component sizing, architecture of the power train [32].

2. Equipment and their Connections for HEVs

The following design shows the architecture of HEV with block representations of each component. There are mainly eight components in a HEV. These are as follows and are discussed one by one.

a) HEV Battery Assembly
b) Power Cable
c) Power Management Control Engine Control Unit (ECU) HV- CPU
d) Hybrid Transaxle
- Generator (MG1)
- Motor (MG2)

e) Inverter with Converter Assembly
- Boost Converter
- Inverter
- DC/DC Converter

f) Compressor with Motor Assembly (with Inverter)

g) Engine
h) Auxiliary Battery

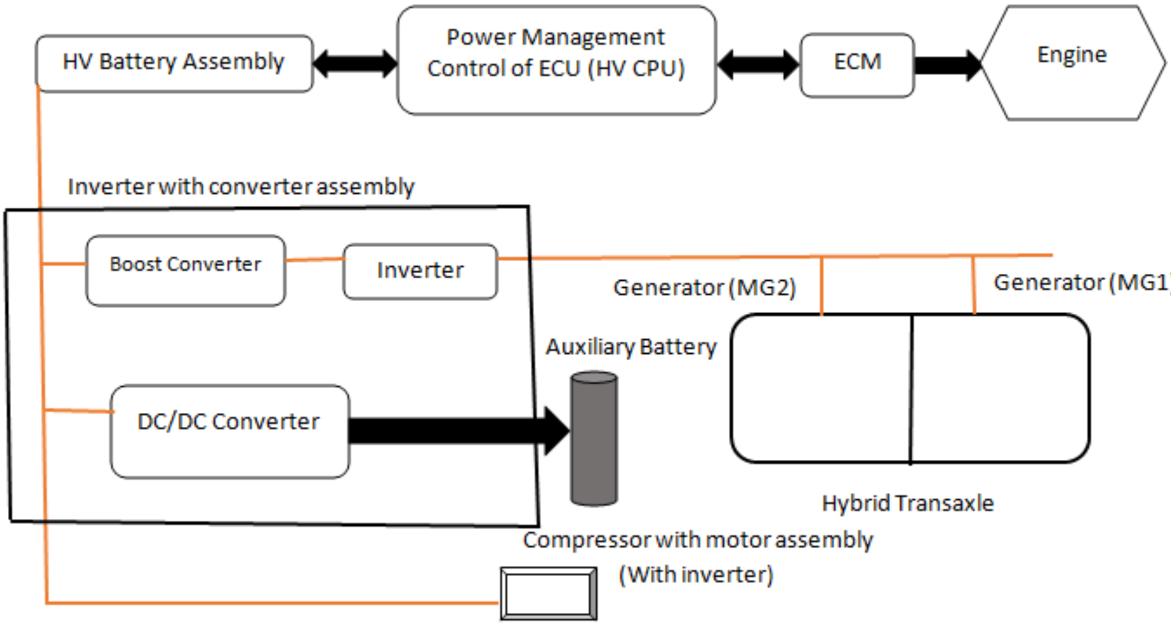

Fig. 3. Hybrid Electric Vehicle Components

2.1 HV Battery Assembly

It stores electricity generated by MG1 and MG2. In order to drive MG1 and MG2, the battery supplies power to the inverter with converter assembly. HV Battery uses lithium-ion cells, and these lithium ions are also used in mobile phones.

2.2 Power Cable

It is high voltage and high amperage cable that connects the high voltage system parts. As it is the carrier of power signal transmission, hence plays a significant role. Due to high voltage, high current, and different environment use, high safety must be ensured before selection of the cable and thus specifications and required details must be monitored for cable materials.

2.3 Power Management Control ECU (HV CPU)

It is used to control the hybrid system and is integrated with the power management control ECU. It receives information about driver inputs and vehicle driving conditions from each sensor as well as from various ECUs. The power management control ECU calculates the required MG2 torque and engine power output. As it controls other subsystems in the vehicle, hence it can be called as the brain of the vehicle.

- Hybrid Transaxle
- Generator (MG1)
- Motor (MG2)

Transaxle includes a generator and a motor and works as a continuously variable transmission. Here in the above connection diagram, is depicted as MG1 and MG2. Generator (MG1): It generates electricity using engine power and functions as starter to start the engine. Motor (MG2): It mainly supplements the power of the engine to enhance driving performance. When driving the vehicle using the motor, the system uses MG2 by itself to drive the vehicle. It generates the electricity using regenerative braking when decelerating the vehicle.

- Inverter with Converter Assembly
- Boost Converter
- Inverter
- DC/DC Converter

It consists of three parts. These are Boost Converter, Inverter, and DC/DC Converter. Boost converter is basically a simple type of switch mode converter. It boosts the voltage supplied by the HV battery and outputs it to the inverter. It reduces the voltage generated by the MG1 and MG2 to charge the battery. Using inverter, it converts DC to AC for MG1 and MG2. It also converts the AC generated by the MG1 and MG2 to DC in order to charge the HV battery. The inverter can create the variation in the speed at which the motor rotates by frequency adjustment of the alternating current. It reduces the HV battery voltage to supply electricity to the electrical components, such as power headlights, interior lights, wiper and window motors, fans, and many other systems within the vehicles. It also recharges the auxiliary battery.

- **Compressor with Motor Assembly (with Inverter):** It is an electrical compressor for the air conditioning. It is operated by the electrical power from the HV battery. As the compressor is equipped with built-in motor, it can operate even when the engine of the vehicle is stopped.
- **Engine:** Engine acts as the heart of the automobiles. It is highly efficient Atkinson Cycle engine (at type of internal combustion engine) designed for the hybrid system. It produces power to drive the vehicle and generate electricity.
- **Auxiliary Battery:** The Auxiliary Battery is used as power source for each ECU and Electrical components such as the audio system, GPS, or turn your radio, or other electrical components.

3. Basic Structure of HEV

Different types of HV configuration have different power flow paths. All the related and co-related concepts are discussed below in the following sub-sections.

3.1 Series Hybrid System

- In series hybrid system, the wheels are driven by motor and generator generates the power needed by motor. The generator is rotated by the engine therefore; this system could be described as an EV equipped with an engine operated generator.
- Engine with low output operates at a steady speed within its most efficient speed range.
- In this system, the electricity generated by the generator charges the battery and also powers the motor to drive the vehicles. Examples are Cadillac Electric Luxury Roadster (ELR), Chevrolet Volt, and Fisker Karma.

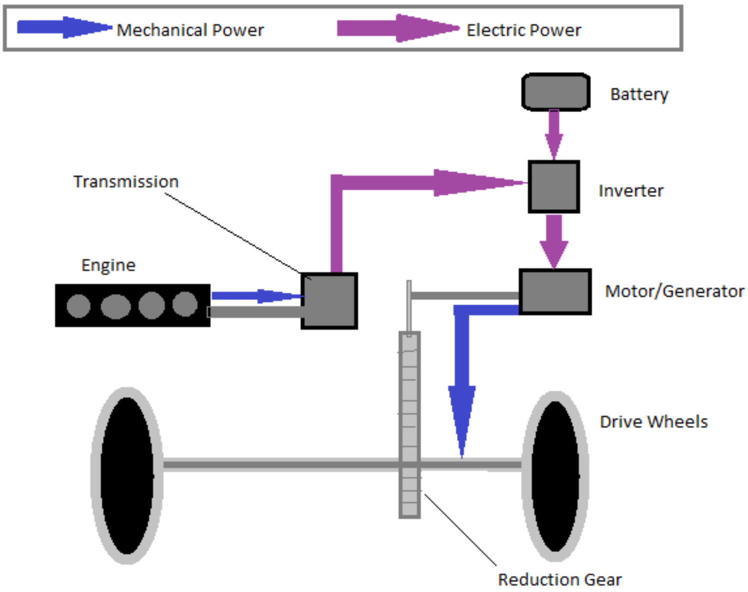

Fig. 4. Series Hybrid System [23]

3.2) Parallel Hybrid System

- In Parallel Hybrid System, both the engine and the motor are responsible to directly drive the wheels.
- Electric motor supplements the power of the engine.
- The system also serves as the generator to charge the high-voltage battery pack while the vehicle is in motion.

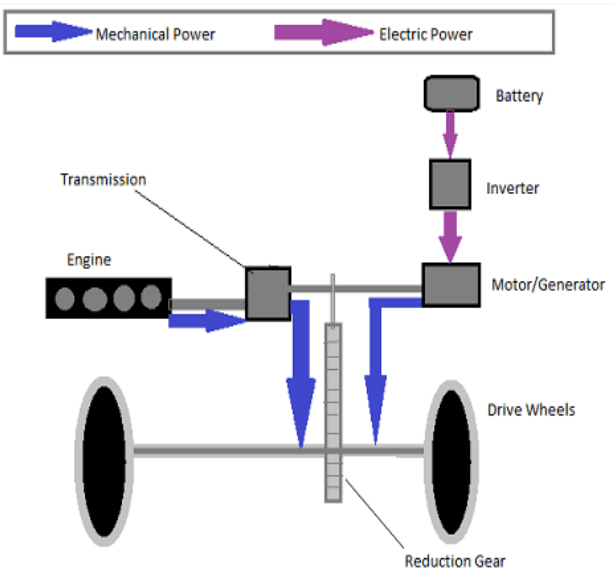

Fig. 5. Parallel Hybrid System [23]

3.3 Series Parallel Hybrid System

In Series Parallel Hybrid System have the functions of both types of Hybrid Systems.

- This system consists of both a motor and a generator.
- In this system, electricity is generated by the generator using engine power.
- The generated electricity is used to charge the HV battery and power the motor.
- The mechanical engine power provided to the power split device can be balanced by the motor. All the above configuration may use more than one motor to drive the vehice.

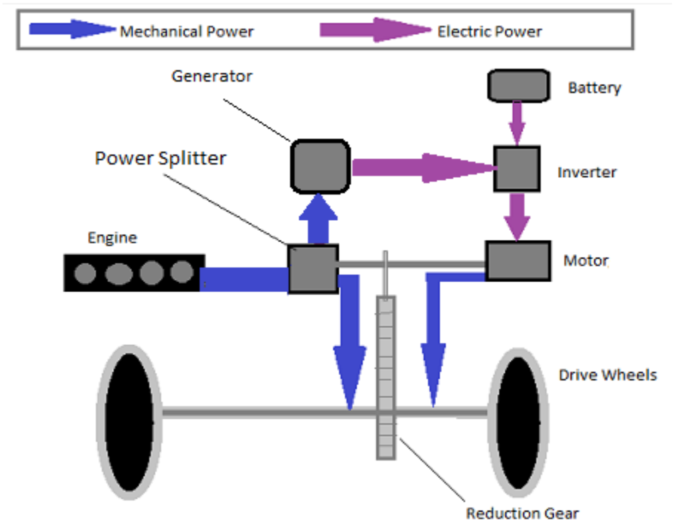

Fig. 6. Series Parallel Hybrid System [23]

4. Formulation of the Electric Drive System for HEV

The Electric Drive System primarily functions to convert Electrical Energy into Mechanical Energy and thus, this function is attained with use of an electric machine or motor [24]. Permanent Magnet Synchronous Motor (PMSM) is used as integral part of the system. Motor torque as a function of speed can be expressed as

$$\tau = \tau_s - K\frac{1}{\omega_{NL}}\omega, \tag{1}$$

where,

τ_s is abbreviated as the small torque,
ω_{NL} is no load rational speed,
K is Constatnt

As a function of rotational speed the motor power can be expressed as

$$P = \tau . \omega \tag{2}$$

PMSM motor phases is configured in wye connection.
State equations for the motor phase current are expressed as

$$\frac{di_a}{dt} = \frac{1}{L}(v_a - i_a R_a - v_{e\_a} - v_n) \ , \tag{3}$$

$$\frac{di_b}{dt} = \frac{1}{L}(v_b - i_b R_b - v_{e\_b} - v_n) \ , \tag{4}$$

$$\frac{di_c}{dt} = \frac{1}{L}(v_c - i_c R_c - v_{e\_c} - v_n) \ , \tag{5}$$

where,
$v_a, v_b, and \ v_c,$ abbreviations denote the phase drive voltages, $R_a, R_b, and \ R_c$ abbreviations denote motor phase resistances.
$v_{e\_a}, v_{e\_b}, v_{e\_c}$ are the phase back emfs and v_n is the neutral point voltage.
A most general used technique to achieve the phase alignment and produce the maximal torque is to change the frame of refrence from stationary A, B, C frame to rotational D, Q frame of refrence. This frame transformation, known as Park's Transformation, basically converts an AC signal into a DC signal in order to simplify the analysis and controls. Since d-axix produces no torque or zero torque, the measured and controlled d-axix current should always be 0 [25]. On the other hand q-axix produces the maximum torque, therefore, the q-axix current should be the actual commanded current. The block diagram of the model is depicted in figure 7.

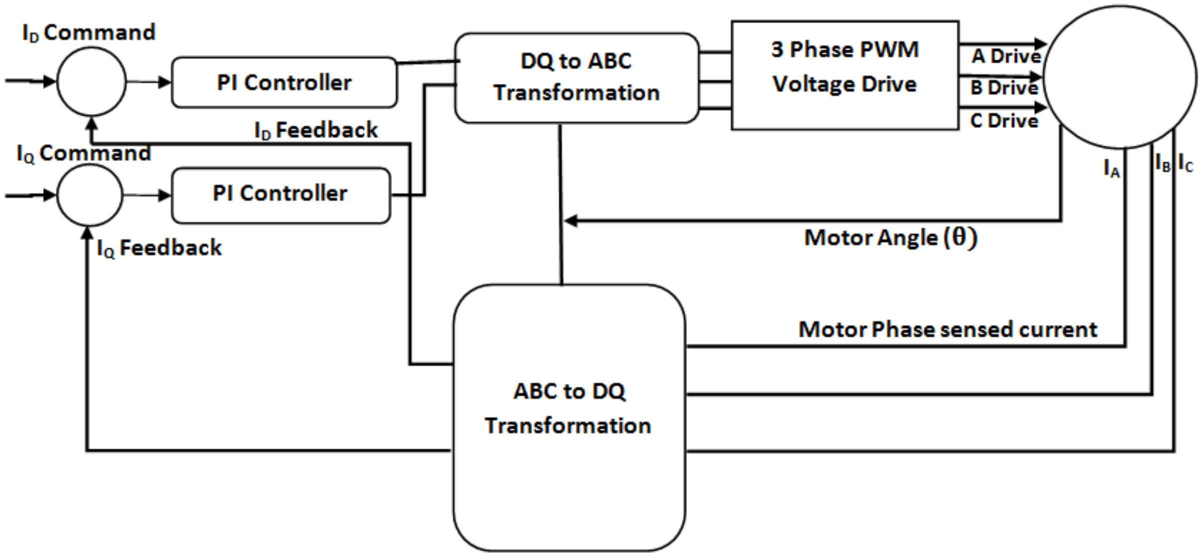

Fig. 7. Closed loop current control

The conversion from stationary frame to the d-q rotating frame leads to the dynamic state equations of the phase currents

$$\frac{di_d}{dt} = \frac{1}{L_d}(v_d - i_d R_s + \omega_m L_q i_q) \tag{6}$$

$$\frac{di_q}{dt} = \frac{1}{L_q}(v_q - i_q R_s - \omega_m L_d i_d + \omega_m \pi_m) \tag{7}$$

And the motor torque is given by

$$T_e = \frac{3}{2}\frac{P}{2}[\pi_m i_q + (L_d - L_q). i_q i_d] \tag{8}$$

Where, P is the number of poles in the electric machine.

Table 2
Discussions of HEV using various mechanisms

Ref.	Framework	Technology	Summary of work	Research Gaps	Remark
[26]	Electric Vehicle	Fuzzy Logic Control	Utilising this technology proves that this kind of controller achieves stable operation with good system performance and response.	HEV with Artificial Intelligence Technology	[26]
[27]	Hybrid Electric Vehicle	Hybrid of ICE & Electric Motor	HEV at lower speeds does not emit the smog balancing its sustainable advantage. During lower speed operation the HEV runs on the electric motor and on IC engine during cruising speeds. Thus, the HEV offers greater milage capacity than conventional.	Solar based HEV	[27]
[28]	Plug-in Hybrid EV (PHEV)	PHEV with battery pack charged through a standard electrical outlet.	PHEV using battery pack charged through a standard electrical outlet.	Design Considerations (weight, volume, cost) Technological Challenges (Energy storage system, Motor drives, and power electronics)	[28]
[29]	Electric Vehicle	Solar Energy Technology	The solar vehicle is an advance step in saving these non-renewable sources of energy. The basic principle of solar car is to use energy that is stored in a battery during and after charging it through a solar panel. The charged batteries are majorly used to drive the motor which serves here as an engine and moves the vehicle in reverse or forward direction.	Small speed range, initial cost is high. Also, the rate of conversion of energy is not satisfactory (only 17%).	This technology solves many problems related to the environment and is the best pollution free technique. We urgently need to make use of them so that we can reduce our dependence on fossil fuels.
[30]	Solar power system	Artificial Intelligence Based MPPT Technique	Under partial shading condition, the conventional MPPT techniques are incapable of tracking the global maximum power point (GMPP). Hence Artificial Intelligence technique has been primarily deployed for maximum power point tracking (MPPT) in the solar power system.	The failure of MPPT could be caused by the inability of the algorithm to search for GMPP. It will be stuck at the local MPP and thus cannot produce the optimal power output.	The AI-based MPPT technique exhibits good convergence speed, small oscillation at steady state and accurate tracking, even under PSC or faster change of irradiance.

The novelty of this research is to find a hybrid artificial intelligence-based technique for achieving the optimum response of HEVs. Table 2 shows the critical analysis of the HEVs which provide a better configuration with an artificial intelligence system. Using this new research, further experiments can be conducted by researchers to get the maximum output.

In addition, the fuzzy logic approach has an insensitive property to various disturbances, such as the driver's driving pattern, service route state, and load conditions, due to the robust characteristic of it. As further research, fuzzy logic with more kinds of information can be performed for efficient driving of the HEV [33]. Researcher uses the Analytic Hierarchy Process (AHP) as an analytical technique to analyse the results of Focus Group Discussions (FGD) in order to find suitable possible renewable energy resources that can assist Malaysia [34]. The review's goal is to present a thorough method for producing lactic acid from algae biomass. It begins with a discussion of the many types of algae, other microorganisms that are involved, fermentation technology, and technological limitations [35].

6. Conclusions

Energy crisis and environmental concerns have led the development of EV. The major challenges being faced are that it could not fulfil the customer's need because of its short range of driving and high initial costs. However, HEV can satisfy consumer's need currently and will grow with high pace. Engineers/Researchers are putting efforts in the way to optimize the multiple sources of energy in order to achieve best fuel economy or very low emission at lower cost. These content gives an overview of HEV focussing on its architecture, configuration types with well-illustrated description, and the importance of environmental protections.

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