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Review Article

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Abstract

A hybrid vehicle was first patented by William H Patton in 1889. With the development of technology, hybrid electric vehicles are now stepping up to contribute to reducing fossil fuel dependency. This ultimately contributes to climate change. Hybrid vehicles, due to their advanced technology allow flexibility in choosing any of the available fuel choices. A hybrid electric vehicle (HEV) is a kind of hybrid vehicle which combines an internal combustion engine (ICE) system with electricity for propulsion (also known as a hybrid vehicle drivetrain). This is to achieve more efficient and cheaper fuel consumption with better performance. There are various HEVs and the usage dependency of each electric vehicle differs by its design. The most common form of HEV is a hybrid electric car, however hybrid electric trucks (pickups and tractors) and buses also exist. This paper aims at a detailed review of research in this area.

Keywords: Hybrid Electric Vehicles, review, electrical variable transmission, regenerative braking, electric drives, energy storage, fuel cells, supercapacitor, batteries.

Introduction

The growing demand for fossil fuels as a power source clearly affects the climate and becomes expensive day by day. This demand for fossil fuels keeps growing exponentially, and they are becoming scarce. So, to reduce the dependency on these fossil fuels, there exists a need to improve the vehicle's efficiency and provide an alternate and dependable power source. This requirement for a more reliable power source created a path to create a vehicle which operates under the influence of multiple power sources, which are called as Hybrid Vehicles. The hybrid vehicles which use electricity as a power source, are known as Hybrid Electric Vehicles (HEVs)

The idea of a hybrid electric vehicle was first conceived in 1889 by William H Patton who filed a patent application for a gasoline-electric hybrid rail-car propulsion system and for a similar hybrid boat propulsion system later. These vehicles consisted of an internal combustion engine (ICE) which was connected to a generator used to charge lead-acid batteries in parallel with the traction motors. This led to the testing of a series-parallel controller for a traction motor, ultimately resulting in the use of a tramcar in 1891 and the sale of a street-railway locomotive to a company in 1897.

The ICEs were linked to a dynamo flywheel that was coupled to an onboard battery as they became more sophisticated over time. In order to save energy, the battery was charged using the dynamo and regenerative braking. Henri Pieper of Germany/Belgium debuted a hybrid car in 1905 that was powered by a tiny gasoline engine, batteries, and an electric motor/generator. It used both motors to accelerate or climb a slope, and it used the electric motor to charge its batteries while cruising. The Woods Motor Vehicle electric car manufacturer soon produced an electric motor with a four-cylinder internal combustion engine under the moniker Dual Power in 1915. The car was propelled solely by its electric motor

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below 15 mph (24 km/h), which was powered by a battery pack. Above this point, the "main" engine engaged to propel the car to its top speed of 35 mph (56 km/h).

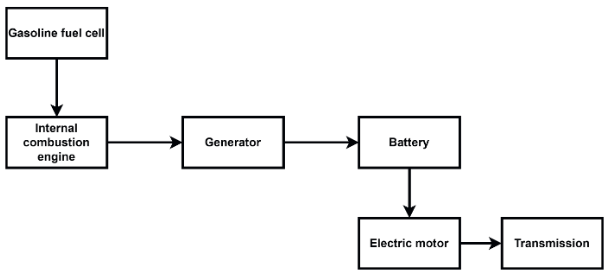

Fig. 1 Block diagram of series hybrid electric vehicle

Table 1: Difference between conventional vehicle and hybrid electric vehicle

Conventional Vehicle	Hybrid Electrical Vehicle
Power train: IC engine	Power train: Engine and Motor
High specific power	Low specific power
Low specific energy	High specific energy
Greenhouse gas emissions and more noise	No emission and less noise
Less cost and weight	More cost and weight
More maintenance and running cost	Less maintenance and running cost
No recovery of braking energy, engine efficiency ~ 30%	Recovery of energy by regenerative braking, engine efficiency ~ 80%

Types

A typical hybrid vehicle consists of two abundantly available fuel options. Such as:

1. Fossil Fuels – Coal, Petrol, Diesel, LPG
2. Electricity – Battery Operated
3. Human Operated
4. Chemical – Hydrogen
5. Biofuel
6. Nuclear Fuel – Compact Nuclear Power Plant, Fuel Cells, etc.

Hybrid Vehicles are classified into three types:

1. Full Hybrid Electric Vehicle (FHEV)
2. Mild Hybrid Electric Vehicle (MHEV)
3. Plug-in Hybrid Vehicle (PHEV)

Full Hybrid Electric Vehicle:

A FHEV is a vehicle which can run completely on any single source (either fossil fuel or electrical source) for power. They can be configured to use both of their power sources in series or parallel mode i.e., the two power sources can be used alternatively (in a symbiotic manner) or both at the same time.

Mild Hybrid Electric Vehicle:

An MHEV requires both of its power sources (both electrical and other source) to work. Any single source, independently cannot run the vehicle at the required speeds. It is limited by its technology and cannot overcome the advantages of a FHEV.

Plug-In Hybrid Electric Vehicle:

The PHEV, as the name suggests requires a source of fuel, such as electricity or hydrogen, etc. They can be plugged into a power socket whenever possible, and ultimately have a higher storage capacity and longer duration of travel than the FHV.

Electric energy is a cleaner and more efficient source of power if not a safer source to control. As a result, it is a primary candidate for an alternative source yet to replace fossil fuels. We find many such hybrid electric vehicles already being used in the world. Submarines employ diesel engines when they surface the ocean and batteries when submerged. Electric cars, such as the Toyota Prius and Chevrolet Volt, use an ICE with a battery-operated system, connected in a series or parallel mode of operation. Yachts – in modern Yachts, the primary mode of power source is ICE along with solar photovoltaic cells (PV cell).

Electrical Braking

There have been at least four kinds of braking methods devised for the applications of electric vehicles. The main goal of these braking mechanisms is to disperse, conserve, and recycle as much energy as effectively possible. They are mentioned below.

1. Regenerative Braking:

The purpose of regenerative braking is to conserve energy. As energy can neither be created nor destroyed, the kinetic energy of a vehicle in motion can be transformed into electrical energy to prevent it from being wasted as heat during a regular breaking procedure. The percentage of braking energy and its traction energy can be up to 40% of the drive cycle energy of the vehicle which can be conserved, this ultimately helps improve the overall efficiency of the vehicle. During acceleration and maintaining a constant speed electrical energy is consumed from the battery, but during regenerative braking, the direction of power flow reverses.

When an electric machine's torque is aligned with the system speed, it draws electrical power from the battery and functions as a motor. Conversely, when an electric machine's torque is aligned with the system speed, it obtains mechanical power from the load and transfers converted kinetic energy to the battery.

When the speed torque is both positive and negative, how does the electrical machine function? So how does a machine produce torque that is negative? Regenerative braking is the process by which a vehicle rapidly reduces its speed when the driver applies the brake pedal in an attempt to slow down the vehicle. This occurs because the power converter now applies less voltage than the machine has developed as a result of the vehicle's kinetic energy, allowing power to flow from the machine to the battery.

It occurs as a change in velocity from a faster to a slower pace, and energy is restored faster. The machine does not create enough braking torque at high speeds to allow for acceleration from zero, so in order to bring the vehicle down to zero speed, it is utilized in conjunction with the friction brakes. However, this system might not be able to meet the vehicle's complete stopping requirements. The driver only needs to release the throttle pedal to apply the brakes when using one pedal, because regenerative braking may be so efficient.

1. Rheostatic Braking:

Rheostatic braking, aka dynamic braking, generally works on the principle of dissipating the heat that is generated through the conversion of mechanical energy from the wheels into heat by passing the generated electricity through multiple resistors, which heat up and allow the dissipation into its surroundings. This braking system works under the principle of a motor working as a generator as it converts the mechanical energy from the shaft into electrical energy. Different types of motors can be used for rheostatic breaking, but they have a few limitations. Dynamic braking can be achieved using permanent magnet motors by simply shorting the terminals, this will stop the motor suddenly, however, this will result in the motor itself getting heated causing damage.

Hence, it is limited to the usage of very low-power applications and unfit for high-traction applications. This method can be further upgraded by keeping the temperature constantly in check, using sensors and a set of cooling fans in the system with thermal monitoring as required. When the temperature of the system exceeds a certain limit, it should be switched off and mechanical braking applied.

2. Plugging Braking:

This braking method quite simply requires the reversal of the supply terminals; this results in the back emf to be in the same direction as the line voltage causing a flow of a high value of braking current back into the system along with torque [1].

3. Combined Braking [2]:

The above-mentioned braking methods are quite innovative and efficient in conserving energy, Permanent Magnet Synchronous Motors (PMSM) such as brushless direct current (BLDC) motors are used. BLDC motor in various recent development fields is found to be quite useful, especially for multi-quadrant operations. They generally use trapezoidal waveform of back EMF (Eb) in most LEVs (Light Electric Vehicles) as it is cheap and efficiently controlled by Hall Effect sensors to detect position during phase commutation, as the waveform is like that of a DC motor. Both of the braking methods listed below can achieve braking torque, yet the system performance of the two hybrid braking methods is dissimilar.

a. Plugging-Regenerative: The combination of both plugging and regenerative schemes is known as the Plugging-Regeneration method. The breaking current can be calibrated through the duty cycle of the power switcher. The breaking time is comparatively shorter. Higher power can be consumed at the DC Bus.

b. Dynamic-Regenerative: The combination of both dynamic and regenerative schemes is known as the Dynamic-Regeneration Method. The breaking current through the stator windings can be calibrated by adjusting the duty cycle of the power switcher. The breaking time is comparatively longer. Lesser power can be consumed at the DC Bus.

Transmission

A transmission system helps the vehicle achieve high speeds with less torque while consuming minimal energy. This is done by applying gears that vary in diameter and size while connected to a single shaft and allowing the conversion of torque from the engine into increased speeds (in rpm) through the shaft.

However, in the perspective of HEVs, the transmission system may be required only during the use of the ICEs, whereas the electric motor may only require a transmission with a fixed gear. This is because an electric motor can achieve up to 15,000 rpm and accelerate from 0 to 100 kmph speeds in 10 seconds.

There exist various types of transmission systems for applications in Electric Vehicles, such as Manual, Automatic, Continuous Variable Transmission (CVT), and Electrical Variable Transmission (EVT) [4].

1.Electrical Variable Transmission (EVT) [5]:

An EVT can be a continuously variable transmission. It is a transmission system that is electromagnetic and works as a starter generator to allow higher efficiency in power consumption. It is designed to provide various input terminals to be utilized in HEVs. It allows the decoupling of the ICE, ultimately allowing optimal fuel usage. With the advantage of higher efficiency and higher speed ranges, this transmission system allows significant improvement in performance and greater reduction of noise, resulting in output power regulation [6].

2. Continuous Variable Transmission (CVT):

The CVT can perform countless ratios within a set limit and can easily change the gear ratio without interfering with the power flow. The gear/transmission ratio can be altered by recalibrating the pulley diameter allowing the vehicle to reach optimal speed within its range ultimately resulting in higher efficiency. There is an advantage of flexibility to decouple during maximum velocity and acceleration, resulting in better performance [4].

Drives

The drives of a HEV are basically a combination of an ICE and an AC/DC source motor. These drives are so connected in the vehicle's design that they can be used alternatively, together at once, along with other diverse design types.

In an HEV, the primary choices for drives are:

DC Series Motor:

Also known as series universal motors, consist of a single voltage supply while the field and rotor windings are in a series connection. This results in greater starting torque with less current, although it acquires high speeds as the torque decreases. Hence, consist reduced speed regulation. During the increase in load, a decrease in back EMF is seen. These motors can be taken as self-excited motors as they operate on a single voltage source [7].

Brushless DC Motor (BLDCM):

As the name suggests, BLDCM does not use brushes and commutators but rather uses permanent magnets. They provide greater torque at greater efficiencies and are preferred to be used as a HUB motor in many hybrid vehicles. Considering them as actuators provides higher resistance with the capability to greater speeds. It has two types of motors that are PMSM and Permanent Magnet Brushless DC Motor (PMBLDCM), each having different characteristics of output waveforms of back EMF [8].

Permanent Magnet Synchronous Motor (PMSM):

PMSM are generally mistaken with BLDC because they produce similar torque generation and usage of permanent magnets. Their field excitation can be obtained by putting permanent magnets on the rotor to generate a constant flux, eliminating the DC source and the losses from field winding and maintenance of slip rings and brushes. They provide trapezoidal back EMF. They are high in efficiency and power density resulting to be more preferred in the automobile industry driving up the costs. They are not self-starting and require a controlled variable frequency stator drive.

Induction Motor (IM):

IMs are generally taken as robust but cheap in cost. A benefit of low starting torque is attained. DTC (Direct Torque Control) methods are used for maximum performance for torque control. For maximum efficiency, the torque changes directly with the flux but inversely to speed. This optimized flux control allows a decrease in acoustic noise. They can be made to reflect an efficiency of 0.92 to 0.95 [9].

Switched Reluctance Motor (SRM):

SRM can be taken as a salient pole with the exemption of the field winding. The rotor is a squirrel cage rotor with some teeth removed in accordance with our required number of poles. As the magnetic field of the stator is in alignment with the rotor, the reluctance of the drive becomes minimum. There is a benefit to high rotational speeds at high temperatures, apart from the exemption requirement of rare earth metals for construction [4].

Energy Storage

An Energy Storage (ES) device in layman's terms is called a battery. There have been various developments in this field, to name a few such as the usage of supercapacitors (SC), fuel cells, etc.

1. Batteries: The devices capable of storing and converting chemical energy into electrical energy on demand can be defined as a battery. There are various kinds of batteries all the way from simple low-energy AAA batteries to control your IR remote control to high-energy Li-ion batteries and more to power heavy electric cars and even submarines. Typically, a battery releases electrical energy when its components undergo an electrochemical reaction allowing electron flow to neutralize the charge across the terminals. This occurs commonly by triggering a redox reaction, i.e., Reduction and Oxidation Reaction - Reduction of Hydrogen and Addition of Oxygen [11].

2. Supercapacitors (SC): The supercapacitors store electric charge by the method of double layering methods instead of storage in an electric field. The double layering method improves the plate area while decreasing the gap among the plates. They have a very high number of cycles in their lifespan and hence are long-lasting than traditional batteries or simple capacitors [11,12].

3. Fuel Cells (FC): Fuel cell uses chemical energy, but from a fuel (preferred hydrogen-oxygen) to perform a redox reaction that generates a flow of electric charge. They consist of charge terminals and electrolytes. The anode and cathode allow the flow of charged ions between them producing electricity while acting as a catalyst. They mostly form H2O including some other products [11,12].

Scope

There is an ever-increasing demand for fuel which is limited only to a few decades, during which the use of ICE-powered vehicles would be highly expensive, while also contributing to global warming. In time, the requirement to replace expensive ICE-based transportation would be replaced by low-cost electrically powered vehicles. Research on Lead-Acid Batteries, Nickel-Metal-Hydride (Ni-MH), Zinc-Air, and Fuel Cells are taking place to verify vehicular performance under various speed gradients, where fuel cells have more promising developments [10]. Although there exists a need for major developments in drive efficiency, power consumption, and power storage systems, there are various approaches to developing the "Hybrid Electric Vehicle" technology for a more weightless, efficient, and cost-effective usage in the automobile industries for futurized vehicles.

Conclusion

At present HEVs may not be a good choice for everyone as HEVs are more expensive than regular gasoline engines. In future, it will be more affordable because of the growth in new technologies with suitable motor control. The transition between electric vehicles and conventional vehicles are more facilitated by hybrid EVs. Better battery management could increase the efficiency of EVs. Hybrid EVs are more ecologically powerful due to their superior electric powertrains and effective internal combustion engines.

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