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Hybrid Electric Vehicle: An Overview of Technology

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Abstract

This article examines and explains the many HEV architectures and operating concepts, including as series hybrids, parallel hybrids, and series-parallel hybrids. The function of regenerative braking in hybrid electric vehicles (HEVs) is also covered; it allows energy to be recovered during braking and deceleration, improving total energy efficiency. The article also looks at key issues including battery technology, energy management plans, and powertrain integration that need to be considered while building hybrid electric cars. It also showcases developments in the sector, like plug-in hybrid electric cars (PHEVs), which allow for external charging and provide an expanded driving range when using only electricity. The advantages of hybrid electric vehicles for the environment are discussed, with a focus on how they can lessen reliance on fossil fuels and greenhouse gas emissions. There is also discussion of the financial issues, such as the price and market acceptance of HEVs.

Keywords: Electric vehicle, battery, hybrid vehicle, ICE, efficiency, traction motor, charging.

INTRODUCTION

When it comes to addressing the drawbacks of traditional internal combustion engine (ICE) vehicles, like excessive fuel consumption and pollution, hybrid electric vehicles, or HEVs, have shown great promise. This essay gives a general review of the technology underlying hybrid electric cars, emphasising its main elements, and working theories. The basic concept of a hybrid electric vehicle (HEV) combines an internal combustion engine with one or more electric motors and an energy storage system, usually a battery pack. The amalgamation of these constituents facilitates enhanced fuel economy and diminished emissions, alongside an array of functional modes that maximise efficacy contingent upon driving circumstances.

A noteworthy advancement in the search for environmentally friendly transportation options is the creation of hybrid electric vehicles, or HEVs. With concerns over rising fuel costs, environmental pollution, and the depletion of fossil fuel reserves, HEVs have emerged as a viable alternative to traditional internal combustion engine (ICE) vehicles. Hybrid electric vehicles (HEVs) combine the advantages of internal combustion engines and electric motors to provide better overall performance, lower emissions, and increased fuel efficiency. This paper provides an overview of the technology behind hybrid electric vehicles, exploring their key components, operational modes, challenges, benefits, and prospects. It aims to shed light on the fundamental concepts and advancements in HEV technology, contributing to a better understanding of this rapidly evolving field.

Hybrid electric vehicle technology is centred on the combination of an internal combustion engine, electric motor or motors, and an energy storage system. This integration allows for the optimization

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of power delivery and energy management, resulting in enhanced efficiency and reduced environmental impact. By utilizing the electric motor(s) in conjunction with the internal combustion engine, HEVs can harness the advantages of both power sources, such as the high-power output of the engine and the instantaneous torque and regenerative braking capabilities of electric motors.

The various varieties of hybrid electric cars, such as series, parallel, and series-parallel hybrids, will be covered in detail in this essay. Each type possesses a unique architecture and operational mode, determining how the power sources are utilized under various driving conditions. The importance of regenerative braking will also be highlighted, as it enables the recovery of energy during deceleration and braking, subsequently improving energy efficiency.

Designing and engineering hybrid electric vehicles present various challenges that need to be addressed. Powertrain integration, including the seamless coordination of the internal combustion engine, electric motor(s), and energy storage system, is a critical aspect. Effective energy management techniques are required to guarantee ideal distribution and utilisation of power. Furthermore, battery technology developments are essential for enhancing energy storage capacity, longevity, and overall performance.

The environmental benefits of hybrid electric vehicles are substantial. HEVs have the potential to significantly reduce greenhouse gas emissions, mitigate air pollution, and decrease reliance on fossil fuels. Moreover, the economic aspects of HEVs, including their cost, market adoption, and potential for energy savings, will be discussed. The primary concerns of the twenty-first century are energy conservation and environmental preservation, which has sped up the planning and development of electric vehicle technology. Electric vehicles (EVs) provide zero emissions, the creation of a new automobile sector, economic growth, and an effective and intelligent transportation system. Additionally, EVs with artificial intelligence systems will enhance current road usage and traffic safety. The energy storage components of an electric vehicle (EV) system include different kinds of batteries, fuel cells, and ultra-capacitors.

If they can schedule charging times ahead of time, though, the customer will be informed of the available slots. Thus, customers have the option to look at slots other than those that are already in a queue. Good charging infrastructure will also aid in lowering consumers' "range anxiety" by responding to their questions and assuaging their concerns about the charging network [1, 2].

LITERATURE SURVEY

A new generation of engineers may better understand the fundamentals of hybrid vehicle technology and propel its advancement with the invaluable guidance found in Modern Hybrid Electric Vehicles. The writers discuss fuel cells, off-road hybrid vehicle systems, hybrid electric, plug-in hybrid electric, hybrid hydraulic, and fully electric vehicles. They concentrate on these vehicles' propulsion and power systems, covering topics like energy and power management [3].

Along with the standard coverage of the powertrain system electric motor, battery, DC/DC converter, and charger Yangsheng Xu et al. [4] also thoroughly covers sophisticated control methods, anti-noise online state of charge estimate, fast charging, cell equalisation, and energy management. A revolution in vehicle design concepts is also brought about by the transformation of the vehicle powertrain system, which replaces the conventional mechanical gearbox system with driving-by-wire and control-by-wire technologies. It is feasible to implement novel features like battery and energy system management, 4-wheel independent driving (4WID), and 4-wheel independent steering (4WIS).

Kumar et al. [5] include electric propulsion, the vehicle's body, and an energy management system that combines technology from the fields of electrical, electronics, mechanical, automotive, and chemical engineering. They have presented the current state-of-the-art permanent magnet brushless DC motor drive for the electric car application. Energy storage devices, an EV's smart energy management system unit, and the advantages and commercial elements of EVs are also addressed.

Extensive study has been conducted on electric vehicles (EVs) as a potentially effective means of mitigating the greenhouse impact. When compared to internal combustion engine vehicles (ICEVs), plug-in hybrid electric vehicles (PHEVs) offer competitive driving range and fuel efficiency because of advancements in power electronics, energy storage, and support. The performance of the plug-in hybrid electric vehicle (PHEV) could be greatly increased by using energy management systems (EMS) or better control algorithms. The workings of the various EV types will be detailed in this review study. We'll also talk about the prospect of using supercapacitors and batteries to boost PHEV energy capacity.

The workings of the various EV types will be detailed in the review study of Ding et al. They explained about the prospect of using supercapacitors and batteries to boost PHEV energy capacity [6].

CONSTRUCTION

The construction of EV includes major following parts discussed below with their functions and depicted in Figure 1.

1. *Chassis and Body:* The construction of an HEV begins with a chassis, which provides structural support and serves as the foundation for the vehicle. The chassis is typically made of high-strength steel or aluminum alloy to ensure strength and rigidity while minimizing weight. The body of the vehicle is then constructed around the chassis, using materials such as steel, aluminum, or composite materials to balance strength, safety, and weight considerations.
2. *Internal Combustion Engine (ICE):* The ICE, which may be a gasoline or diesel engine, is mounted in the front of the vehicle. It is typically like the engines used in conventional vehicles and is connected to the drivetrain.
3. *Electric Motor(s):* Electric motors are strategically placed in the vehicle to provide propulsion assistance and enable electric-only operation. They are usually located near the wheels or integrated into the transmission system. The battery pack powers the electric motors, which can be either AC or DC motors.

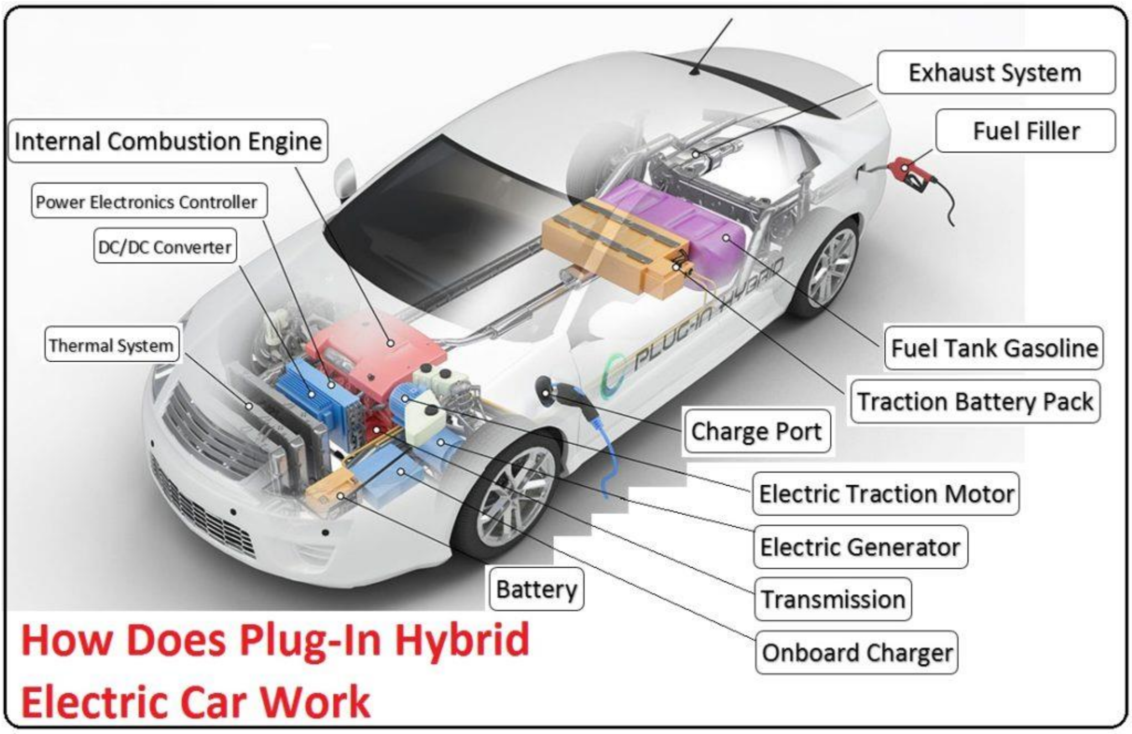

Figure 1. Construction of Hybrid Electric Vehicle.

4. *Battery Pack:* The battery pack, which stores electrical energy, is a crucial component in HEVs. It is usually positioned underneath the floor or in the back of the car to maximise weight distribution. To supply the necessary voltage and capacity, the battery pack is made up of separate battery modules or cells coupled in series and parallel combinations. The construction of the battery pack ensures safety, thermal management, and efficient energy storage.
5. *Power Electronics:* Parts of power electronics, such as converters and inverters, control the electrical energy transfer between the battery pack and the electric motors. They convert and regulate the voltage and current to match the requirements of the motor(s) and ensure efficient power distribution.
6. *Transmission System:* The transmission system in an HEV varies depending on the design and drivetrain configuration. A specialised gearbox, like a dual-clutch or continuously variable gearbox (CVT), might be a part of it to maximise power transfer between the electric motor(s), ICE, and wheels. The transmission system enables seamless and efficient transfer of power based on driving conditions.
7. *Control Systems:* To regulate the interaction between the ICE, electric motor(s), battery pack, and other components, HEVs rely on complex control systems. These control systems include electronic control units (ECUs) and software algorithms that monitor and optimize power flow, energy management, and overall vehicle performance.
8. *Regenerative Braking System:* HEVs incorporate a regenerative braking system, which includes components such as sensors, actuators, and controllers. The electric motor(s) are activated by the system to act as generators during braking or deceleration, transforming the kinetic energy into electrical energy that is stored in the battery pack.

WORKING

The working of a hybrid electric vehicle (HEV) involves the coordinated operation of its various components to achieve optimal efficiency and performance. An overview of how a HEV operates is provided in Figure 2:

1. *Start-Up and Idle:* When the driver starts the vehicle, the control system checks the state of charge (SOC) of the battery pack. If the SOC is sufficient, the vehicle can operate in electric-only mode during low-demand situations like idling or low-speed cruising. Propulsion power is produced by the electric motor(s), which take energy from the battery pack.
2. *Acceleration and Low-Speed Driving:* During acceleration or low-speed driving, both the internal combustion engine (ICE) and electric motor(s) work together to provide the required power. Based on variables like driver input, vehicle speed, and battery state of charge, the control system calculates the ideal power distribution between the internal combustion engine (ICE) and electric motor(s). The electric energy transfer between the battery pack and the electric motor or motors is controlled by the power electronics.
3. *Regenerative Braking:* The regenerative braking system kicks in when the driver hits the brakes or slows down. The vehicle's kinetic energy is transformed into electrical energy by the electric motor(s), which operate as generators. The battery pack is subsequently recharged with this energy, increasing overall energy efficiency, and increasing the range of electric vehicles.
4. *Power Distribution and Energy Management:* The control system balances the power going to the electric motor(s) and the ICE by continuously monitoring the driving circumstances. It determines the most efficient operating mode, such as parallel mode (both ICE and electric motor(s) working together) or series mode (ICE charging the battery, electric motor(s) driving the vehicle), to achieve the desired performance and fuel efficiency.
5. *Battery Charging:* During periods of low power demand or excess power from the ICE, the control system prioritizes charging the battery pack. This is done through the ICE or by utilizing excess power from regenerative braking. The power electronics ensure efficient charging and prevent overcharging or discharging of the battery pack.
6. *Electric-Only Mode and Hybrid Mode:* Depending on the battery SOC and driving conditions, the vehicle can operate in electric-only mode or hybrid mode. When the car is in electric-only

mode, the battery pack provides all the power for the electric motors. In hybrid mode, both the ICE and electric motor(s) work together, with the control system optimizing power distribution for maximum efficiency.

7. *Idle-Stop and Auto-Start:* HEVs often feature idle-stop functionality, where the ICE shuts off automatically when the vehicle is stationary, such as at traffic lights. The control system smoothly restarts the ICE when the driver lets go of the brake pedal. During idle times, this feature lowers emissions and conserves gasoline.

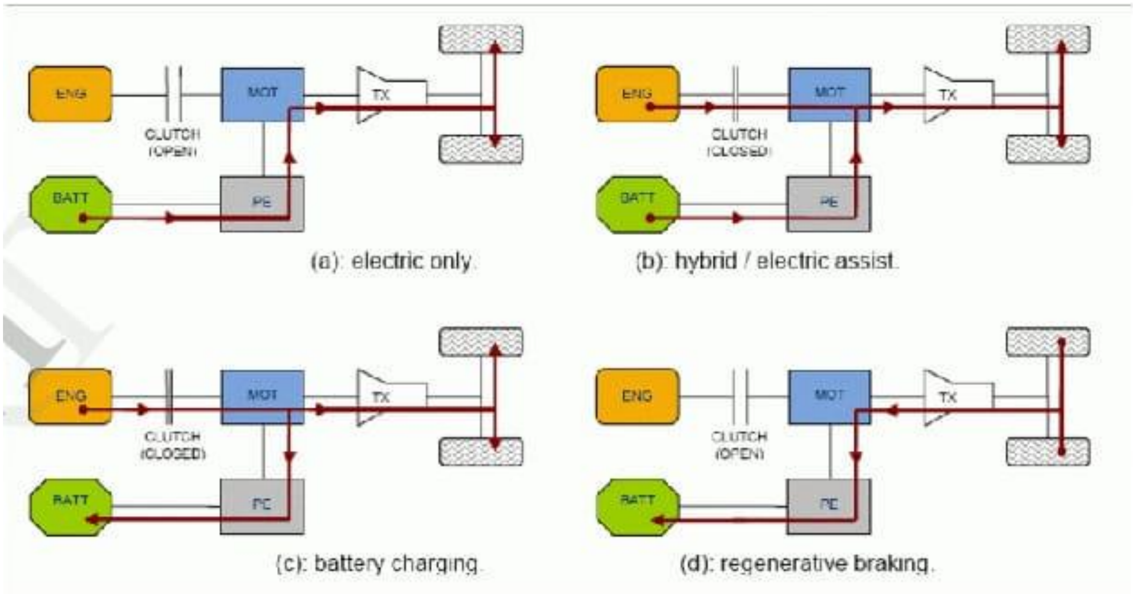

Figure 2. Working of Hybrid Electric Vehicle.

Charging Infrastructure Point of View

When travelling by highway between cities, quick DC charging is a useful technique for shortening the recharging time and increasing the range. Planners of EV infrastructure should consider the fact that different driving habits need different amounts of energy and time to recharge. Range anxiety can be reduced by designing EV recharging infrastructure properly and dynamically [6].

Owners of electric vehicles might worry that they won't have enough fuel to get to their destination because these vehicles often have a shorter driving range than conventional ones. Even though EVs' range is increasing, some drivers still find it difficult, especially those who must travel large distances [7]. Precise estimation of energy consumption and drivable range can be achieved by using a mathematical vehicle model that can forecast "real road" driving energy consumption and drivable range. Third, creating charging stations across the nation can also help reduce range anxiety, but this requires cooperation between the public and commercial sectors as well as government incentives. Finally, a network path selection model can be used to reduce range anxiety. This model uses an algorithm to determine the best and fastest route for electric vehicle drivers. In the meanwhile, these models could be enhanced by determining the length of a halt at a charging station and the time of departure. Using highly efficient electric motors in series, parallel, and series-parallel charging configurations can extend the driving range. Some EV manufacturers also offer free rental cars for short excursions outside the EV range to help reduce range anxiety [8].

The Electric Grid

A complex integrated network of electricity-generating sources (usually power plants), large-capacity transmission lines, smaller-capacity localised distribution lines, and associated equipment makes up the electric utility system [9–10]. Due to the grid's existing incapacity to economically store huge amounts of electricity, the amount of electricity generated must be carefully matched with the amount of customer demand at any one time. With a variety of generating plants that can match generation to load in real time, the electricity system balances power generation with consumer demand. There are two ways that PEV use may impact the grid. [11–12] Their presence results in a growing demand on the grid, particularly as they are embraced in ever-larger numbers. However, they also have the potential to improve grid stability in several ways.

Implementing Electric Vehicles Present Difficulties

Utilities, state and local governments, and private sector participants such as EV service providers, fleet employees, and individual automobile owners are examples of public sector operators in the EV market. Diverse operational decisions are made by variable adopters, which include private vehicle owners, managers of private company fleets, and public fleet operators. At-home charging, public charging, and battery-swapping stations should be optimised for the charging models based on the types and distribution of adopters. Infrastructure rollout and incentive programmes are also related to the type of client. This definition classifies as a "EV" any car in which an electric battery provides the majority of the driving force. (For instance, plug-in hybrid electric cars (PHEVs), battery electric vehicles (BEVs), and plug-in electric vehicles (PEVs). The only source of power for a BEV is its battery pack, which may be charged using the grid. PHEVs, on the other hand, are powered by an internal combustion engine, an electric motor, and a battery that can be charged from the grid. "PEVs" are another term for BEVs and PHEVs, which are EV models that can be charged with grid electricity. The most widely used battery substitute for electric vehicles (EVs) is lithium-ion, which is followed by lead-acid, nickel-metal hydride, and sodium-nickel chloride batteries. An electric vehicle's battery can be recharged at different charging levels. Level 1 or level 2, also known as conventional charging, requires 2 to 8 hours to fully charge a battery at 110 to 240 volts. Level 3 (480 V), also known as rapid charging, only takes 20 to 40 minutes. The cost of an electric vehicle's battery is still high. The price of lithium-ion battery bundles for electric vehicles (per kWh) is expected to decrease to USD125 by 2022 from as high as USD800 in 2012. Battery degeneration occurs during storage, which is equivalent to yearly ageing, as well as during charging and discharging.

There are various ways in which the EV sector is different from the traditional ICV industry, which makes growing EV service operations more challenging.

RESULTS AND DISCUSSION

The goal of an electric car is to outperform its internal combustion counterpart in terms of affordability, performance, comfort, safety, and dependability while maintaining a commercially feasible range. The automotive industry and researchers currently favour permanent magnet brushless direct current motors due to their high-power density, small size, dependability, noiselessness, and low maintenance needs.

BENEFITS OF EV

The technology of hybrid electric vehicles, or HEVs, has several benefits and improves both the efficiency and environmental impact of transportation. The key benefits of HEVs are summed up as follows:

1. *Greater fuel economy:* Internal combustion engines (ICEs) and electric motors are combined in HEV architecture to increase fuel efficiency. For low-speed driving and acceleration, the internal combustion engine (ICE) is used less frequently thanks to the electric motors. Compared to traditional cars, this leads to reduced fuel consumption and improved fuel economy.
2. *Lower Emissions:* Compared to conventional automobiles, hybrid electric vehicles emit fewer pollutants and greenhouse gases into the environment. The internal combustion engine (ICE) can be tweaked to run more effectively and produce less pollutants even when it is operating. The electric motors produce no tailpipe emissions when they are powered only by electricity. By cutting emissions, we can lessen the effects of climate change and enhance air quality.
3. *Energy Efficiency:* Hybrid electric vehicles (HEVs) can recover and store energy during braking and deceleration thanks to a technology called regenerative braking. The electric motors are then

powered by this energy, thereby eliminating the requirement for the ICE. Hybrid electric vehicles (HEVs) are more energy efficient than traditional automobiles because they recycle and absorb energy that would otherwise be wasted as heat.

FUTURE SCOPE

1. *Advancements in Battery Technology:* HEVs rely on battery packs for storing electrical energy. Future advancements in battery technology will concentrate on lowering costs, enhancing charging rates, and boosting energy density. Advancements may include the use of solid-state batteries, lithium-air batteries, or other emerging battery technologies that offer higher energy storage capacity and faster charging times.
   The second type of electric car that combines the advantages of both HEVs and BEVs is the plug-in hybrid electric vehicle (PHEV), which has larger battery packs that can be charged externally. The future scope of PHEVs lies in expanding their electric-only range and infrastructure development to support widespread adoption. As a result, PHEVs would be able to run exclusively on electricity, decreasing their dependency on internal combustion engines and thereby cutting emissions.
3. *Increasing Electric-Only Range:* Future HEVs may feature improvements in electric motor efficiency, battery technology, and overall vehicle design to extend the electric-only range. This would further reduce fuel use and emissions by enabling HEVs to run on electric power for longer distances.
4. *Flexibility and Range:* Hybrid electric vehicles (HEVs) can run on electricity alone for brief distances, which lowers the amount of fossil fuels used and emissions produced in urban areas. The driving range is increased by combining ICE and electric power, getting around the drawbacks of fully electric cars and allaying range anxiety.

CONCLUSION

To achieve better fuel economy, lower emissions, and higher performance, hybrid electric vehicles (HEVs) offer a promising technology that combines the advantages of internal combustion engines (ICEs) and electric motors. By integrating power sources, such as ICEs, electric motors, and battery packs, HEVs can optimize power delivery and energy management, resulting in greater overall efficiency.

HEVs employ regenerative braking to capture and store energy during deceleration, further improving energy efficiency and extending the electric driving range. Through the reduction of air pollutants and greenhouse gas emissions, they also help to create a cleaner and greener environment.

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