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RESEARCH ARTICLE OPEN ACCESS

Why Electric, Hybrid, and Fuel Cell Vehicles

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ABSTRACT

With the more stringent regulations on emissions and fuel economy, global warming, and constraints on energy resources, the electric, hybrid, and fuel cell vehicles have attracted more and more attention by automakers, governments, and customers. Research and development efforts have been focused on developing novel concepts, low-cost systems, and reliable hybrid electric powertrain. This paper reviews the state of the art of electric, hybrid, and fuel cell vehicles. The rapid consumption of fossil fuel and increased environmental damage caused by it have given a strong impetus to the growth and development of fuel-efficient vehicles. Hybrid electric vehicles (HEVs) have evolved from their inchoate state and are proving to be a promising solution to the serious existential problem posed to the planet earth. Not only do HEVs provide better fuel economy and lower emissions satisfying environmental legislations, but also they dampen the effect of rising fuel prices on consumers. HEVs combine the drive powers of an internal combustion engine and an electrical machine. The main components of HEVs are energy storage system, motor, bidirectional converter and maximum power point trackers (MPPT, in case of solar-powered HEVs). The performance of HEVs greatly depends on these components and its architecture. The topologies for each category and the enabling technologies are discussed.

I. INTRODUCTION

A well-knit and coordinated transportation provides mobility to people and goods. The transportation sector mainly consists of road, railway, ships and aviation, where road transportation consumes 75% of the total energy spent on transportation. The automobile industry plays a significant role in economic growth of the world and hence affects the entire population. Since vehicles mostly run on internal combustion engine (ICE), the transportation industry is accountable for 25%–30% of the total green- house gases emission [1]. ICE works in the process of fuel combustion resulting in the production of various gases like CO 2, N O 2, NO and CO [2] which cause environmental degradation in the form of greenhouse effect and are responsible for their adverse effect on human health. To overcome this, the transportation industry is trying hard to manufacture vehicles that can run on alternate power sources. Electric vehicles (EVs) were tried as a solution in 1881 where battery alone propelled the vehicle and there-fore required a bulky battery pack. Absence of an ICE handicapped these vehicles with a short driving range [3].

Hybrid electric vehicles (HEVs) were conceptualized to bridge the power of ICE and the emission-free nature of EVs. HEVs offer better fuel efficiency over ICE-based vehicles and generally work in charge-sustaining (CS) mode where the state of charge (SOC) of battery is main- tained throughout the trip. The issue with CS mode is that its charging efficiency relies mainly on regenerative brak- ing and gasoline, so plug-in HEVs (PHEVs) were con- ceptualized as a possible solution. Unlike HEVs, PHEVs have the additional facility to be charged externally through power outlets. Most of the power in a PHEV is derived from an electric motor (EM) which acts as a pri- mary source, while ICE acts as a backup. As the battery SOC reaches a particular threshold, the PHEV behaves like a regular HEV, and the ICE kicks in and acts as a primary power source. The PHEVs mainly work in charge depletion (CD) mode where SOC is depleted up to a threshold level.

PHEVs extend the all-electric range, improve local air quality and also may have grid connection capability. Another possible approach for extending the electric range of an HEV is to allow continuous charging of the battery while running. The emergence of solar-driven A well-knit and coordinated transportation provides mobility to people and goods. The transportation sector mainly consists of road, railway, ships and aviation, where road transportation consumes 75% of the total energy spent on transportation. The automobile industry plays a significant role in economic growth of the world and hence affects the entire population. Since vehicles mostly run on internal combustion engine (ICE), the transportation industry is accountable for 25%–30% of the total green-house gases emission [1]. ICE works in the process of fuel combustion resulting in the production of various gases like CO 2 , N O 2, NO and CO [2] which cause environmental degradation in the form of greenhouse effect and areresponsible for their adverse effect on human health. To overcome this, the transportation industry is trying hard to manufacture vehicles that can run on alternate power sources. Electric vehicles (EVs) were tried as a solution in 1881 where battery alone propelled the vehicle and there- fore required a bulky battery pack. Absence of an ICE handicapped these vehicles with a short driving range [3]. Hybrid electric vehicles (HEVs) were conceptualized to bridge the power of ICE and the emission-free nature of EVs. HEVs offer better fuel efficiency over ICE-based vehicles and generally work in charge-sustaining (CS) mode where the state of charge (SOC) of battery is main- tained throughout the trip. The issue with CS mode is that its charging efficiency relies mainly on regenerative brak- ing and gasoline, so plug-in HEVs (PHEVs) were con- ceptualized as a possible solution. Unlike HEVs, PHEVs have the additional facility to be charged externally through power outlets. Most of the power in a PHEV is derived from an electric motor (EM) which acts as a pri- mary source, while ICE acts as a backup. As the battery SOC reaches a particular threshold, the PHEV behaves like a regular HEV, and the ICE kicks in and acts as a primary power source. The PHEVs mainly work in charge depletion (CD) mode where SOC is depleted up to a threshold level. PHEVs extend the all-electric range, improve local air quality and also may have grid connection capability.

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Compared to conventional vehicles, hybrid electric vehicles (HEVs) are more fuel efficient due to the optimization of the engine operation and recovery of kinetic energy during braking. The PHEVs are charged overnight from the electric power grid where energy can be generated from renewable sources such as wind and solar energy and from nuclear energy. Fuel cell vehicles (FCV) use hydrogen as fuel to produce electricity, therefore they are basically emission free. When connected to electric power grid (V2G), the FCV can provide electricity for emergency power backup during a power outage. Due to hydrogen production, storage, and the technical limitations of fuel cells at the present time, FCVs are not available to the general public yet. HEVs are likely to dominate the advanced propulsion in coming years. Hybrid technologies can be used for almost all kinds of fuels and engines. Therefore, it is not a transition technology; hybrid control theory and optimization of vehicle control. This paper provides an overview of the state of the art of electric vehicles (EVs), HEVs and FCVs, with a focus on HEVs. why EV, HEV, and FCV? It also looks at the key issues of HEVs and FCVs. Section III reviews the history of EVs, HEVs, and FCVs. the engineering philosophy of EVs, HEVs, and FCVs. Section V presents the architectures of HEVs and FCVs. the current status of HEVs and FCVs. the key technologies, including electric motor technology, power converter technology, control and power management technology, and energy storage devices. Finally, conclusions are given in **WHY EVs, HEVs, AND FCVs?**

Vehicles equipped with conventional internal combustion engines (ICE) have been in existence for over 100 years. With the increase of the world population, the demand for vehicles for personal transportation has increased dramatically in the past decade. This trend of increase will only intensify with the catching up of developing countries, such as China, India, and Mexico. The demand for oil has increased significantly. Another problem associated with the ever-increasing use of personal vehicles is the emissions. The greenhouse effect, also known as global warming, is a serious issue that we have to face. There have been increased tensions in part of the world due to the energy crisis. Government agencies and organizations have developed more stringent standards for the fuel consumption and emissions. Nevertheless, with the ICE technology being matured over the past 100 years, although it will continue to improve with the aid of automotive electronic technology, it will mainly rely on alternative evolution approaches to significantly improve the fuel economy and reduce emissions. Battery-powered electric vehicles were one of the solutions proposed to tackle the energy crisis and global warming. However, the high initial cost, short driving range, long charging (refueling) time, and reduced passenger and cargo space have proved the limitation of battery-powered EVs. The HEV was developed to overcome the disadvantages of both ICE vehicles and the pure battery-powered electric vehicle. The ICE can be stopped if the vehicle is at a stop, or if vehicle speed is lower than a preset threshold, and the electric motor is used to drive the vehicle along. The ICE operation is optimized by adjusting the speed and torque of the engine. The electric motor uses the excess power of the engine to charge battery if the engine generates more power than the driver demands or to provide additional power to assist the driving if the engine cannot provide the power required by the driver. Due to the optimized operation of the ICE, the maintenance of the vehicle can be significantly reduced, such as oil changes, exhaust repairs, and brake replacement. In addition, the onboard electric motor provides more flexibility and controllability to the vehicle control, such as antilock braking (ABS) and vehicle stability control (VSC). FCVs use fuel cells to generate electricity from hydrogen. The electricity is either used to drive the vehicle or is stored in an energy storage device, such as battery pack or ultra-capacitors. Since fuel cells generate electricity from chemical reaction (isothermal), they do not burn fuel and therefore do not produce pollutants. The byproduct of a hydrogen fuel cell is water. An FCV provides quiet operation and more comfort for the ride. Although HEVs possess many advantages, they also have certain limitations. The main concerns include increased cost due to the introduction of motors, energy storage system, and power converters; reliability and warranty related issues due to the lack of electrician in the car shops; safety concerns due to the introduction of high voltage in the vehicle system; and electromagnetic interference caused by high-frequency high-current switching in the electric powertrain system. Issues related to FCV include the high cost of the fuel cell, storage of hydrogen, production and transportation of hydrogen, and life cycle of the fuel cells.

HEV: The flip

Ever since Lohner-Porsche, the first HEV, was developed in 1901, the automobile industry has come a long way. In the recent years, HEV technology has gained tremendous boost in terms of research and development. There is a general sense of optimism in the industry in regard to this new technology. While discussing the many advantages of HEV, often the shortcomings are overlooked. This tech- nology is still in a relative inchoate state and has certain below-mentioned inherent shortcomings that need addressing in order to become a mainstream product

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Shortcoming;

1. **Limited range:** An HEV has a comparatively restricted range. Considering that an HEV ought to generate minimal amount of energy from the ICE, the distance per charge is relatively small. There have been improvements apropos of this variable. Further, an HEV requires a minimum of 30 min to charge fully, whereas a traditional car would require barely five minutes to fill the complete tank.

2. **Low power:** A traditional vehicle is equipped with a powerful ICE which allows it to provide tremendous speed and torque. In HEV, the combination of ICE,EM and pack of batteries makes it bulky and eats up the extra space. In the bid to reduce the weight and cost, an HEV is equipped with a weaker engine and smaller motor, which gives less speed and torque. Owing to this fact, faster cars have not been able to transit to this eco-friendly technology. There have been attempts to break this image, with a prominent example being Tesla’s Model S vehicle, but the cost of the car is well beyond the common man’s budget. Adding fuel to the fire, an ICE is more durable than amotor which has many sensitive components.

3. **Expensive:** The major concern that holds back the buyer’s intention to purchase a hybrid vehicle is its cost that makes it $5000–$10000 costlier than

conventional cars. But, the features of HEV like lower running cost and tax exemptions can compensate for this rise in cost up to large extent.

4. **Maintenance costs:** The complex structure of HEV leads to high maintenance cost along with it and also gives rise to the need of highly skilled technicians and mechanics for repair.

5. **Batteries :**Considered to be the weakest link in the chain, the battery required to store energy has always posed a challenge in HEV technology. Lithium-ion-based batteries are the most common batteries used in HEVs owing to its high energy density. But such batteries invite a whole set of problems, such as its high sensitivity to external environment, weight and cost. Compared to the traditional ICE, a battery is more susceptible to variations in temperature and is heavier. The final nail in the coffin is that the material s used in the creation of the battery itself are hazardous to the environment, hence vitiating the ultimate objective of being a green technology. The risk of human life during an accident is exacerbated due to the additional risk of electrocution from the in an HEV.

6. **Security:** A HEV requires a controller for the optimum usage of ICE and electric motor power trains. With the increased dependence on smart solutions, security proves to be an ever present danger. Remote exploitation may result in illegal access to unsavoury people. It may result in huge losses for an individual if not wary. Unlike a traditional ICE which still requires physical contact to stop or disable a vehicle, an HEV is vulnerable to remote attempts. As such great precautions and protocols need to be developed to keep consumers safe.

7. **Critical analysis:** Several critics also claim that an HEV simply delays the inevitable due to its continued consumption of fossil fuels. In order to provide more power or increase the distance, an ICE is coupled with the motor. As such, an HEV only reduces the rate of fuel burning in ICE. With current estimates indicating the exhaustion of fossil fuels in the recent future, some critics are sceptical of the utility of HEVs

Scope for improvement

There are many front where the technology can grow be it in the adaptation, dissemination or penetration of HEV in the market. Being quite advantageous over conventional vehicles, it has some weaknesses in terms of efficiency, re fuelling, cost and many others. Some important thrusts of focus are listed below

1.Battery issues: The battery plays a vital role in HEV performance. They are quite heavy and expensive and thus impact the cost of HEVs. The performance of a battery is affected by temperature variations; therefore, an efficient battery management system is required. It needs long charging time and is sensitive to over/undercharge. Number of charge/discharge cycles decides the durability of battery. Further, disposal of toxic waste of battery is a big issue. Resolving these issues will allow the BEVs to run on the road.

2. Public awareness :Public awareness and participation is very crucial to infiltrate HEVs in their lives. Various media and education can make people conscious about the advantages of this alternate transport. Participation of government, private players and cost-effective schemes will encourage consumers to use hybrid vehicles.

3. Smart charging infrastructure: The charging infrastructure needs to be built at regular intervals so that these vehicles can be used for long journeys.

4. Impact on grid: EVs and PHEVs mostly are charged by being plugged into the power outlet continuously for several hours. So, increase in these vehicles will increase the load on grid and power system performance issues. Hence, the need for extra generating units will arise. The electric power available in vehicles can also be banked at the grid using vehicle to grid (V2G) concept which is relatively unexplored at present. This concept works on the balancing of the'off-peak' and 'peak' demands.

5. Cost: Due to high prices of the batteries used in HEVs, EVs and PHEVs, these vehicles are not affordable to middle-income groups who comprise the major portion of the population. The advancement in control strategy, battery management system and less costly component utilization will decrease the purchase and operational costs which will attract more people to buy such vehicles.

II. CONCLUSION

This paper has presented an overview of the state of the art of EVs, HEVs, and FCVs. With the ever more stringent constraints on energy resources and environmental concerns, HEVs will attract more interest from the automotive industry and the consumer. Although the market share is still insignificant today, it can be predicted that HEVs will gradually gain popularity in the market due to the superior fuel economy and vehicle performance. Modeling and simulation will play important roles in the success of HEV design and development. Control is the prime key technology in HEVs, hence the control theory of HEVs should be further advanced.

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