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Study of Electric Vehicles

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Abstract- **Electric vehicles (EV) are getting more commonplace in the transportation sector in recent times. As the present trend suggests, this mode of transport is likely to replace the internal combustion engine (ICE) vehicles in near future. Each of the main EV components has a number of technologies that are currently in use or can become prominent in the future. EVs can cause significant impacts on the environment, power system, and other related sectors. The present power system can face huge instabilities with enough EV penetration; but with proper management and coordination, EVs can be turned into a major contributor to the successful implementation of smart grid. The transport sector is one of the biggest emitter of CO2 and hence it is very important to convert the sector to a green sector. Indian government has come up with ambitious plans of introducing the EVs to Indian market and keep in pace with the development of EVs globally. The National Electric Mobility Mission Plan 2020 (NEMMP 2020) has come with a detailed report on the EVs.**

Index terms- **EVs; conventional HEVs; PHEVs; plug-in hybrid electric vehicle; energy transmission; battery technology; FC; PV; internal EMS; EMS; energy management system**

INTRODUCTION

The Indian automobile industry is all-set to embrace vehicles without an IC engine and a hydrocarbon fuel. The powerful purpose and the need for a cleaner environment along with dependency upon fossil-fuels are ready to create a major disruption. As per the Society of Manufacturing of Electric Vehicles, the population of e-vehicles is growing at the rate of 37.5% in India. India aspires to become 100% EV nation by 2030. However, one of the major roadblocks in the growth of e-vehicles envisaged by SMEV is availability and viability of charging infrastructure in India. In the light of the above background, it makes a compelling objective to study the commercial viability of e-vehicles and charging infrastructure required for it. Hence, it is proposed to investigate and perform detailed study on the first of its kind pilot project in India for deployment of 100 e-vehicle units by an application based fleet operator and its collaboration with an Oil company for providing charging infrastructure. An electric vehicle is powered by one or more electric motors, using rechargeable batteries which have electrical energy stored in it. Electric motors give electric cars instant torque, creating strong and smooth acceleration. Electric vehicles (EVs) are considered to be superior technology than internal combustion engine vehicle from an efficiency and environmental perspective. EVs, are about four times as efficient as vehicles with an internal combustion engine at using the energy delivered to the vehicle to overcome vehicle road load.

CLASSIFICATIONS OF ELECTRIC VEHICLE

Taking the power supplement and propulsion devices into account, EV could be classified into three different types: pure electrical vehicle (PEV), hybrid electrical vehicle (HEV) and fuel cell electrical vehicle (FCEV) (Chan and Chau, 2001; Chau, 2010, 2014). Table 1 shows a brief classification of different EVs. The PEV is purely fed by electricity from the power storage unit, while the propulsion of PEV is solely provided by an electric motor. The driving system of HEV combines the electric motor and the engine, while the power sources involve both electricity and gasoline or diesel. FCEV is driven by an electric motor and could be directly or indirectly powered using hydrogen, methanol, ethanol or gasoline.

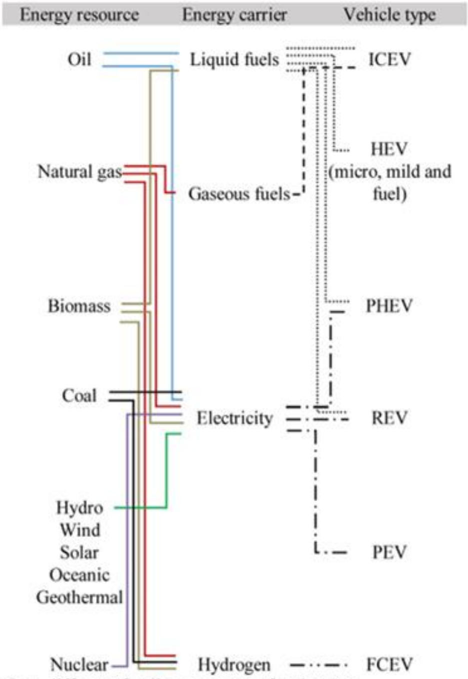
In PEV, loosely named as battery electric vehicle (BEV), energy storage capacity fully depends on the battery technology. Zero discharge emission of PEV should be a significant advantage because the electrical energy is solely supplied from the vehicle-mounted battery. On the other hand, the limitations on the present status of the on-board battery technology of PEV make it less attractive than ICEV under the same economic and driving requirements. Batteries with high power densities but low energy densities result in longer charging time – even with fast charging technologies, one hour to several hours for full charging is necessary. Thus, main challenges of the PEV are limited driving range, high initial cost and lack of charging infrastructures.

For the practical implementation, the size and location of the battery inside the PEV should also be standardised). FCEVs are attractive because of zero roadside emissions. Even taking the overall emissions into account, which include the emission from chemical plants and on-road reformers, the FCEV seems still competitive. Fuel cell (FC) is the main power supplier and the critical technology for FCEV is an electrochemical device that produces DC electrical energy through a chemical reaction. There are five main components in FC: anode, an anode layer, electrolyte, cathode and a cathode catalyst layer. With suitable parallel/series connection of FC sources, the required amount of power can be produced to drive the car. In terms of driving range, it is comparable to ICEV, thus resulting in a wide range of application of FCs from small scale plants of the order of 200 W to small power plants of the order of 500 kW. However, the high initial cost and lack of refuelling stations are still regarded as significant challenges for the success of FCEV. Also, the supply electricity continuity of FCs is less reliable than conventional battery used in EVs.

The crucial advantage of BEV and FCEV is the ‘zero emission’ and hence reduced air pollution. However, the ‘zero emission’ of BEV and FCEV is not absolute considering the emissions during the whole processing. However, “what is critical as the main pollution-contributor and how” are the topics that are hardly discussed. For example, the pollution-contributors include chemical contamination when producing the fuel cell and the battery (or the electrochemical plant for FCs), the emissions during the vehicle manufacture, the pollution from scrap battery processing, etc.

The HEV combines the properties of ICEV and BEV. Driving power sources of HEV include both gasoline/diesel and electricity; the propulsion relies on the engine and electric motor. According to different refuelling or recharging measures, HEVs can be classified as either conventional HEVs or grid-able HEVs.

Based on levels of the combination, the conventional HEV could be further developed to three types: micro, mild and full HEV. The grid-able HEV could be either plug-in hybrid electric vehicle (PHEV) or range-extended electric vehicle. Figure 1 shows different categories of EVs based on the energy source and propulsion device.



based on different feeding measures for the EV.

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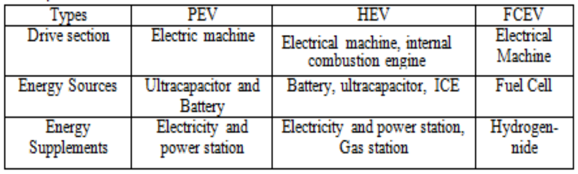
However, the need for engine and gasoline is not eliminated in HEV – so there is no zero emission. The combination of electric generator and engine increases the complexity of the manufacturing process and the initial cost. Therefore, the challenges for HEV are focusing on coordinating these two propulsion devices to achieve an optimal efficiency while reducing the design complexity at the same time (Wong, 2013). Going through the overall development of EVs and considering both the economy and the taking the energy sources into account, EVs are fully or partially energised from the batteries, which themselves are directly or indirectly charged from either a power station and/or electrochemical reactions. Therefore, various renewable energy sources should be used to improve the overall emission of EVs.



Types	PEV	HEV	FCEV
Drive section	Electric machine	Electrical machine, internal combustion engine	Electrical Machine
Energy Sources	Ultracapacitor and Battery	Battery, ultracapacitor, ICE	Fuel Cell
Energy Supplements	Electricity and power station	Electricity and power station, Gas station	Hydrogen-nide

Table 1 - Comparison of different electrical vehicles

Types PEV HEV FCEV

Drive section Electric machine Electrical machine, internal combustion engine Electrical Machine Energy Sources Ultracapacitor and Battery Battery, ultracapacitor, ICE Fuel Cell Energy Supplements Electricity and power station Electricity and power station, Gas station Hydrogen-nide

Technologies of hybrid electric vehicle

1. Micro and mild HEV
2. Full and dual-mode HEV
3. Grid-able HEV (PHEV)
4. Plug-in hybrid electric vehicle technologies
5. The propulsion motor technology in PHEV-Connecting status of motors in PHEV
6. Electro-motor selection for PHEV
7. Range-extended hybrid electric vehicle

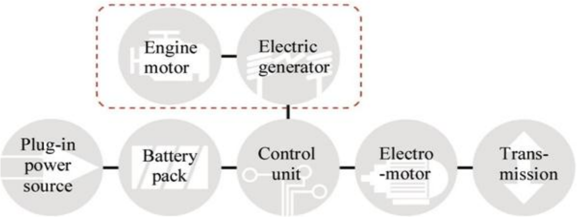


Figure 3 - Series connecting system of PHEV (see online version for colours)

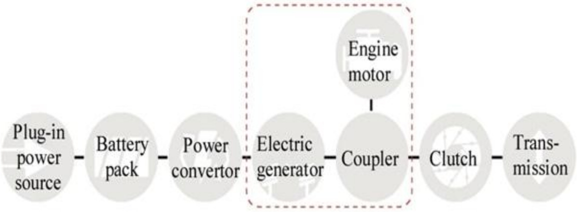


Figure 4 - Parallel connecting system of PHEV (see online version for colours

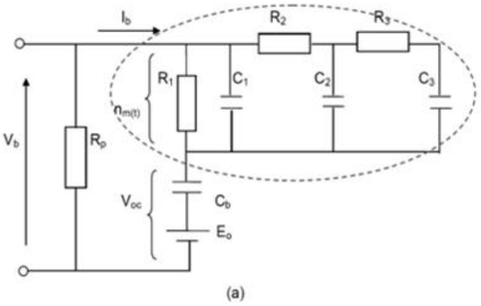
Battery model

For HEV, three types of energy sources modes can be used. The lead acid battery, which is widely used in HEV, provides propulsion .

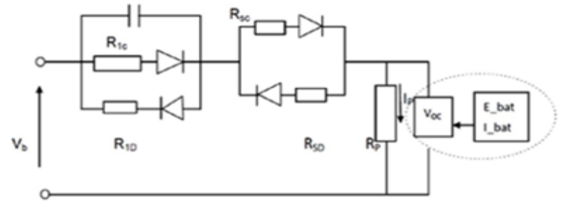
Practically, the characteristics of battery strongly impact the SOC, such as battery capacity, temperature, and lifecycle. It shows three typical battery models – an improved simple battery model, mathematical model and dynamic battery model

The improved simple battery model consists of a constant resistance and an ideal voltage source in series. R1, R2 and R3 with C1, C2 and C3 replace the constant resistance with a variable resistance to act as the internal resistance. The mathematic model takes the voltage and current drops differentiate between internal and overvoltage resistances for charging into account. The dynamic model (Figure 6(b)) introduces two real-time blocks that provide a practical discharging current and the battery energy Ibat and Ebat, respectively. This block also includes the battery temperature data real-time updating .

(a) Improved simple battery model



The battery model can be applied to various categories; the most common application is the polymer Li-ion battery, which originates from the lithium-ion battery with a polymeric material electrolyte replacing the organic solvent (Wang et al., 2016). The storage capacity range of a polymer Li-ion battery is 150–190 W h kg–1, while the power density range is from 300 W kg–1 to 1500 W kg–1 (Saw et al., 2016). A great number of test system models have adopted polymer Li-ion battery (TCL PL 383562) in simulation studies that involve the dynamic battery model (Chen and Rincon-Mora, 2006). With the improvement of the battery technology, zinc-bromide batteries are widely accepted in vehicular applications because of higher energy densities (approximately 300 – 600 W kg–1) (Swan et al., 1994). Compared to other batteries, the electrode of the zinc-bromide battery excludes chemical reaction in the charging process. It acts as the medium for zinc metal plating – zinc is dissolved in the electrolyte during the discharging process (Swan et al., 1994; Mania et al., 2010). At the same time, the lifecycle of the zinc-bromide battery is higher than other traditional batteries. For example, the lifecycle which involves the charging and discharging times of nickel-cadmium (Ni-Cd) rechargeable battery is around 500, while zinc-bromide battery could be charged/discharged 1000–1500 times (Mania et al., 2010). The Ni-Cd battery model, as an example for an improved battery model illustrated in Figure 6(a), has been studied with the simulated data by several researchers (Sperandio et al., 2011; Green, 1999; Paatero, 1997). The Ni-Cd model, however, is not ideal for vehicular implementations since the 'memory effect' negatively impacts the lifecycle when the battery is not completely exhausted during the discharging process.



(b) Dynamic model

Fuel cell model

Theoretically, a single FC can produce about 1.23 V under normal operating conditions of 25□C at 1 atm pressure) (Basu, 2007). FC is based on pure chemical reaction Equation (1) is known as the Nernst equation (Uzunoglu and Alam, 2007), where E0 is the standard potential of the chemical reaction from internal sources (hydrogen/oxygen), R is the universal gas constant, F is Faraday's constant, T is the absolute temperature, and PH2 and PH2O represent the partial pressures of hydrogen and water, respectively. Taking the 'double layer effect' and ohmic overvoltage into account, the total voltage of FC could be expressed as follows:

$$E_{\text{cell}} = E_0 + \frac{RT}{2F} \ln \frac{P_{H_2}\sqrt{PO_2}}{P_{H_2O}}$$

Where Ecell is same as the Nernst voltage in equation (1), Vact is the activation overvoltage in an electrical domain which has the 'double layer effect', and the Vohm is the ohmic overvoltage because of the membrane resistance (Al Baghdadi, 2005). According to Gao et al. (2011), the reduction in the concentration of oxygen/hydrogen in FC might result in a voltage drop (Vcon) shown in equation (3) and the total voltage of FC is thus expressed in equation (4).

$$V_{fc} = E_{\text{cell}} + V_{\text{act}} + V_{\text{ohm}}$$

$$V_{fc} = E_{\text{cell}} + V_{\text{act}} + V_{\text{ohm}} + V_{\text{con}}$$

Where B is the parametric coefficient that refers to different types of cells and operation state, J (A/cm2) is the actual current density through the cell, and the range of Jmax is from 500 mA/cm2 to 1500 mA/cm2. The advanced technology of the proton exchange membrane fuel cell (PEMFC) can be applied to the comprehensive dynamic model. Equation (5) is a dynamic-model consideration of output stack voltage where N is the number of cells in the stack, L is the voltage losses which include activation losses, internal current losses, resistive losses, and concentration losses (Correa et al., 2004; Chiu et al., 2004; Pasricha et al., 2007; Pasricha and Shaw, 2010). When FC model acts as the energy source model in HEV or EV, it could couple with power diode since the reverse regenerative braking. In other words, FC model is associated with power electronic devices such as DC/DC converters.

$$E = N\left\{ E + \frac{RT}{2F}\ln\left\{\frac{P_{H_2}\left(\frac{P_{O_2}}{P_{std}}\right)^{1/2}}{P_{H_2O}}\right\} - L\right\}$$

PHOTOVOLTAIC MODEL

The fundamental principle of the solar cell is utilising the semiconductor solar cell to produce electricity (DC) by absorbing the energy from the solar radiation.

In summary, compared to FC and PV models, the conventional battery model seems to be relatively mature in terms of industrial processing. For the economic practicality, the battery model is also attractive because the high initial cost of FC seems still unacceptable. Another challenge for FC model could be a lack of refilling facilities or the station to exchange FC tank. For PV model, the solar car park is strongly required, which could probably be the main recharging method. Simultaneously, technologies to improve the PV efficiency are also necessary, such as the maximum power point tracking (MPPT). The investments in PV and FC models might pose a significant difficulty for large-scale implementation

POWER ELECTRONICS TECHNOLOGY IN PHEV

The power electronics refers to converters and inverters – DC/AC converter, AC/DC inverter, AC/AC, and DC/DC converters implemented in different scenarios. To improve the reliability and stability of the internal system in EV and HEV, DC/DC converter should be a significant component. In terms of fuel economy, it is possible to involve a power electronic system (Amjad et al., 2010). For a PHEV, the characteristics of the power electronic system are crucial for effectiveness, which include various features depending on selections of power semiconductor devices, converters /inverters, controlling strategies, packing methods of individual units, and the integration of the whole system.

Recent research has revealed that buck converter, boost converter, and cuk converter have been developed with modern technologies, both in terms of packaging and integration. With the use of such DC/DC converter technologies in various vehicular scenarios, the requirements on high-frequency, high-voltage operations, high operating temperature, high ripple current capability, and low equivalent series resistance should be addressed Some studies have introduced a multilevel converter coupled with the cascaded cell for higher propulsion demand to integrate the supercapacitor to improve the efficiency and the energy capacity.

INTERNAL ENERGY MANAGEMENT IN PHEV

The internal energy management demonstrated for PHEV system is different from the EMS for the whole system that includes the charging processing from a power station or smart grids. The definition of internal energy management for PHEV in this paper is an optimised system to achieve the most effective control on the energy transmission. Firstly, it is necessary to introduce a vital function of SOC. As a critical section in HEV, SOC is a connection between the energy source and the energy storage system. Taking an example of the supercapacitor in HEV or PHEV, the SOC can be expressed as follows

$$\mathrm{SOC} = \frac{V_{SC,OC} - V_{SC,\min}}{V_{SC,\max} - V_{SC,\min}}$$

Where VSc, OC is the open circuit voltage of SC, VSC, max and VSC, min are the maximum and minimum open circuit voltages, respectively. In a realistic or practical scenario in HEV, the design of SOC is as follows: the battery is maintaining when SOC is roughly constant (charge-sustaining mode). When ICE is dominating or during a regenerative braking, the battery is only recharged from onboard electricity (charge-depleting mode). These two modes should be operated synergistically in PHEV (Amjad et al., 2010).

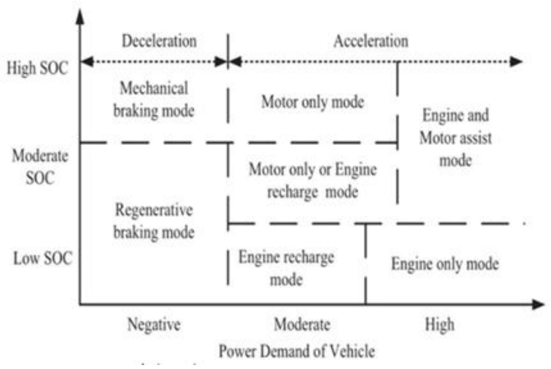


Figure 7 PHEV energy management system operating methods

Based on the design of SOC, control strategy is also a significant issue for improving the efficiency of internal energy management in PHEV. For example, the energy source model of a PHEV adopts an FC model – simultaneously the energy storage model uses SC. Figure 7 shows the energy management system (EMS) operating methods.

SUMMARY ANALYSIS

To minimize the pollution problem and to delay the exhaustion of non-renewable energy sources, there is an urgent and immediate need for replacing the ICEVs with EVs. All studies reviewed so far, however, fail to significantly improve the vehicular functions and driving experiences for various types of EVs. A vital issue is the battery technology. If the battery technology could achieve sufficient energy densities and maintain appropriate power densities at the same time, the use of BEV and FCEV will significantly increase. As a result, the conventional HEVs have adopted sophisticated and complex vehicle-mounted systems at the expense of dramatically increasing the initial cost.

The PHEV is attractive because of technical breakthroughs in rechargeable battery technology. PHEV improves electricity capacity using plug-in charging to provide continuous power. With the additional use of ICE and the external power supply, the size and weight of the battery could be considerably decreased and also reduce the cost.

The problem faced by PHEVs is the optimisation of internal resources. In terms of internal operations, PHEV could achieve the optimal efficiency through establishing or changing a series of operating rules of ICE, electric generator and the battery packs. Another challenge is the EMS for external power sources. The issues of the optimal systems for the networks for charging stations in various circumstances should also be addressed. If it is possible to construct an internal resource optimisation system and the EMS at the same time, the PHEV meets most of the needs for the transport system, even with the restrictions that currently exist in modern battery technologies

CONCLUSION

The features for different types of EVs have been reviewed in this paper. The PEV and FCEV exhibit the most potential to reduce the road-side emission. However, the PEVs have been restricted by the bottleneck of current battery technologies, while the use of FCEVs show reduced reliability. For the different levels of the conventional HEVs, the driving expectation seems very close to the ICEVs. However, the limitations on the high initial cost and heavy weight are unacceptable for the mass market. The hybrid electric vehicle incorporates most advanced technologies and significantly contributes to the environmental protection. PHEVs are considered as potential candidates to compete with ICEVs in terms of driver expectation, driving range and fuel economy. Research shows that supercapacitor, through its high electricity capacity, seems to be very appropriate for implementation in PHEV. To reduce the overall cost in BEV and PHEV, alternative materials and technologies should be explored and researched. The power electronics technology required for the internal energy transmission should also be researched to improve the overall efficiency.

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