A Novel Battery Charging Method for Plug-in Fuel Cell Hybrid Electric Vehicle

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Abstract. The plug-in fuel cell hybrid electric vehicle (PFCHEV) possesses the features of a battery EV and fuel cell hybrid electric vehicle (FCHEV). The PFCHEV provide a remarkably efficient driving range due to the integration of distinct energy sources. However, the range depends on the capacity of the energy sources, such as the battery and hydrogen storage tank. Considering the Indian geographical scenario, there is a lack of hydrogen refuelling stations and technology challenges. However, at present, in India, the technology development and installation of EV battery charging infrastructures enabled with fast charging are rapidly growing to make EVs feasible by solving a range anxiety issues. Therefore, in this paper, a novel battery charging methodology is proposed for PFCHEVs from the grid, DC fast charging station to achieve the desired range. This method may help to optimize the battery size and hydrogen fuel tank capacity without affecting the range of PFCHEVs.

Keywords: Battery charging; driving range; FCHEV; Plug-in EV; Public charging station.

1 Introduction

Nowadays every megacity throughout worldwide severely facing air pollution due to the tailpipe emission of fossil fuel-based vehicles. Therefore, the adaptation of new energy vehicles has become a main research interest for major vehicle manufacturers and academic institutions [1] - [2]. At present, several alternate energy source-based vehicles, such as battery-operated, hybrid, and fuel cells are commercially available for transportation. The hydrogen fuel cell hybrid electric vehicle (FCHEV) has enormous potential for high energy efficiency and zero emission [3]. Compared to the battery electric vehicle (BEV), the FCHEV can achieve a more extended range with a lesser refuelling time [4]. However, when the FCHEV operates in transient states, such as start-up, acceleration or climbing, the response rate of the generation of required electrical energy from the fuel cell is behind the rate of changing load [5]. As a result, the fuel cell system is not able to generate the required power precisely for the above-mentioned operating conditions. A fuel cell system (FCS) is unable to store the energy generated during the regenerative braking due to its unidirectional

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power output flow capability [6]. These parameters may affect the FCHEV driving range, reliability, economy, and durability [7]. Therefore, to eliminate the above-mentioned issue the FCHEV is mostly equipped with an ultra-capacitor or battery as an auxiliary energy storage system [8] - [9]. Such an arrangement of multiple energy sources increases the complexity of the power source unit of the vehicle and it requires an additional energy management methodology (EMM) to make the sources operate efficiently, reliable, and stable [10]-[11]. The EMM manage each energy source and distributes the power effectively according to the demand for power. As a result, improves system efficiency, fuel consumption, and longer lifetime of the energy sources and FCHEV [12]. Usually in FCHEV, the battery capacity is low as compared to pure EV and it is charged through the fuel cell and breaking energy. Here the primary function of the battery is to provide extra power in star-up conditions and unable to help in extend the driving range due to its capacity. Furthermore, in plug-in fuel cell hybrid electric vehicle (PFCHEV) the auxiliary battery support for achieving extending driving range. Here, the battery has a higher capacity and it is charged from the AC mains.

In summary, the majority of work presented in the literature focuses on to solving the range anxiety and technology barrier related to hydrogen fuel cell capacity, operation, and installation of refilling stations. However, very little work is concentrated on the charging method of the battery in the PFCHEV from the external energy sources. Therefore, this paper proposes a novel charging methodology for a PFCHEV battery which will help to increase the driving range by considering the current development and adoption of green energy-based vehicles in India. Section II discusses the existing FCHEV working operation and their energy source management strategies. The proposed charging methodology is presented in Section III and the results are discussed in Section IV. Finally, the conclusions are derived in Section V.

2 Fuel Cell Vehicle

Usually, the FCHEV is called a hydrogen-based electric vehicle which uses hydrogen as a fuel to generate electric power for propulsion. The generic architecture of FCHEV is shown in Figure 1.

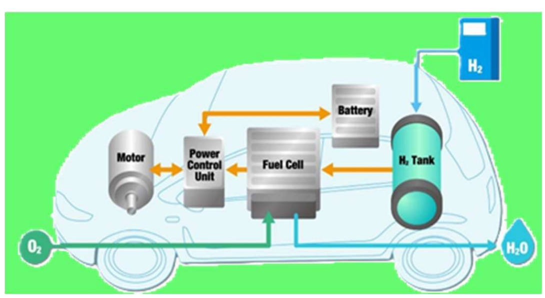


Fig. 1. Generic block diagram representation of FCHEV.

These vehicles offer longer ranges and shorter refuelling times compared to battery-powered EVs. In general, hybrid vehicles are classified as 1) HEV, where vehicles combine two power sources, usually an internal combustion engine and batteries to drive the electric motor, 2) FCHEV, and 3) Plug-in FCHEV here the available auxiliary battery can be charged from the domestic AC power supply instead of on-board charging mechanism. The detailed classification of these vehicles and their energy management strategies are given in [13]. The iterative nature of technology and ongoing advancements have led to the development of hybrid vehicles that combine both electric charging capabilities and hydrogen fuel cell technology. These vehicles aim to provide the benefits of both electric and hydrogen fuel cell vehicles, such as reduced emissions, longer range, and versatile refuelling options. The hydrogen fuel cell system serves as a backup power source for the vehicle when the battery charge is depleted. It can generate electricity to power the electric motor and extend the vehicle's range.

2.1 Energy Management Methodology for PFCHEV

Energy Management System: A sophisticated energy management system controls the flow of power between the battery, the fuel cell, and the electric motor. It determines the optimal use of the electric power stored in the battery and the electricity generated by the fuel cell to maximize efficiency and minimize emissions based on driving conditions and demands. In literature, several EMMs have been reported for FCHEV and their derived architecture. The detailed classification of EMMs is demonstrated in Figure 2. The subsequent subsection discusses the public charging infrastructure for EV battery charging.

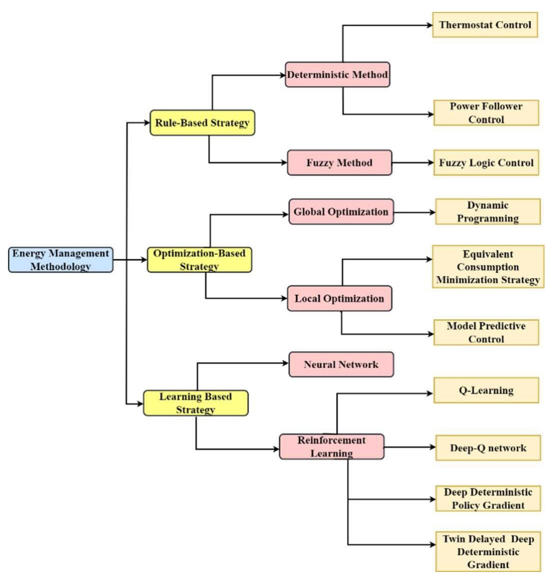


Fig. 2. Classification of Energy Management Methodology [13].

2.2 Public Battery Charging Infrastructure

Rapid and faster adaptation of green energy-based vehicles such as BEV, HEV, FCHEV, and PFCHEV in private and public transportation widely depends on charging infrastructure and refilling stations. Therefore, the government of India making policies incentive plans and various scheme to installation of charger station [14] - [15] These charging stations can be broadly classified as shown in Figure 3 [16].

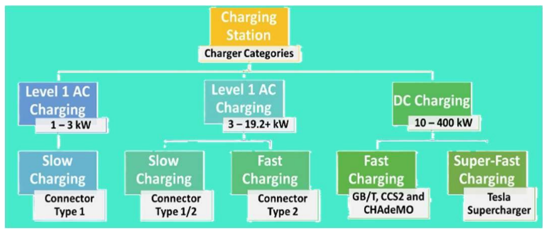


Fig. 3. Generic Classification of Charging Stations

Currently, there are approximately 11,000 public EV chargers in India, with 6,800 being slow chargers and the rest being fast chargers. However, it is projected that by 2030, India will require at least 1.3 million public EV chargers to support the growing number of EVs on the road. Moreover, only two hydrogen refilling stations have been installed in India in comparison to two battery charging stations [17]. There is a huge difference in the installation of battery charging and hydrogen refilling station which demonstrate that in India the FCHEV will take a longer time to gain popularity as compared to BEV. Hence, FCHEV has with additional battery and has it charging with different sources such as onboard charging, AC charging, and DC fast charging. Therefore, the subsequent section discusses the proposed battery charging scheme for the FCEV.

3 Proposed Charging Methodology for PFCHEV

In the PFCHEV, a hybrid vehicle system combines both electric charging capabilities and hydrogen fuel cell technology operating using a combination of both systems to power the vehicle. Figure 4 demonstrates the proposed charging methodology for the PFCHEV. This comprises a proton exchange membrane fuel cell (PEMFC) system which charges the battery and a DC-DC converter is used to maintain the required voltage to the power distribution unit. An in-house developed on-board charger (3.3kW) is used to charge the battery from the AC source as well as a DC charging station such as CCS (shown in Figure 4). Subsequently, the lithium-ion battery is connected to the motor control unit to drive the motor on-demand operating conditions.

By combining both electric charging capabilities and hydrogen fuel cell technology, hybrid vehicles can benefit from the advantages of both systems. The electric charging system provides zero-emission electric driving capability and the ability to charge the battery from an external power source. The hydrogen fuel cell system offers a longer driving range and quicker refuelling time compared to relying solely on a battery. On the other hand, Country such as India already has the

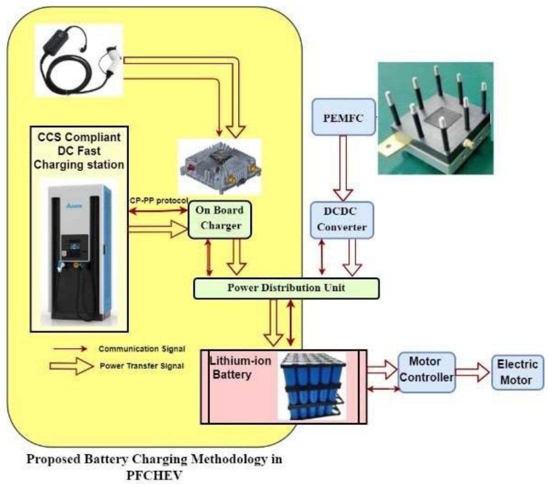


Fig. 4. Block diagram of Proposed Charging methodology for PFCHEV

infrastructure ready for a CCS- based DC Fast charging system, while it will take many years of time for an easily available hydrogen refuelling system. Most of the users need a day of maximum 100 km for daily use, while once or twice they need a higher range such as 400km or so on for travelling. The proposed methodology will take care of both scenarios. This combination allows hybrid vehicles to be more versatile and efficient, utilizing the strengths of both electric and hydrogen technologies to reduce emissions and address range limitations. The next section discusses the experimental results of the proposed methodology.

4 Results and Discussion

This section describes the developed hardware setup to validate and check the effectiveness of the proposed novel battery charging methodology for the PFCHEV. The experimental setup is shown in Figure 5 and it comprises, an AC power supply (AC6804B), High voltage (HV) power supply (N8943A), electronic load (RP7946A), oscilloscope (DL950), CAN communication tool, current probes (701930), developed on-board charger (OBC), and power selector unit.

The in-house developed OBC specifications are given in Table 1. The developed experimental set-up emulates the operation of the proposed charging methodology discussed in Section III. Here, the HV power supply is used to match the voltage level of the CCS fast charging station and the AC power supply is used to represent the grid power supply. The power selector unit consists of the AC and DC contactors to enable or disable the charging from the requested power source, i.e., AC source or DC fast charging station. An electronic load is used to mimic the behaviour of the actual EV battery and it is configured as 100V and 33 A output voltage and current, respectively. Finally, the CAN tool is used for transmitting and receiving signals and communicating with other devices.

Using the development setup, the experiments were performed for the following cases:

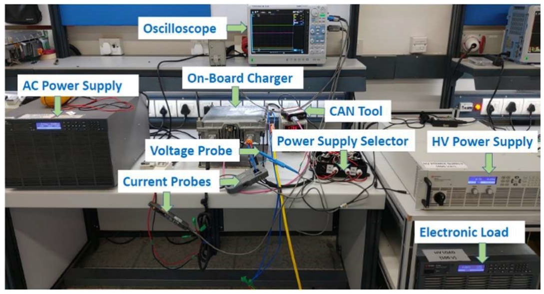


Fig. 5. Experimental Setup

Table 1: The On-Board Charger Specification

Parameters	Specification
AC Input Voltage	160 Vac- 265 Vac
AC Input Current	16 Arms (max)
DC- Input Voltage	200 Vdc-450 Vdc
Output Power	3.3 kW (nominal)
Output Voltage	60 Vdc-130 Vdc
Output Current	32 A Max
Mounting	Inside in Vehicle
Communication	CAN

Case-A. Battery Charging from AC source.
Case-B. Battery charging from HV source (emulate the CCS-based charging).

For Case-A the obtained experimental results were by enabling AC power source, demonstrated in Figure 6. Here, the output current is changed from 5 A to 30 A and again to 5 A to check the charger performance. Moreover, in the zoom view of Figure 5 the input AC voltage and current are aligned in phase which represents that the charger operates at unity power factor.

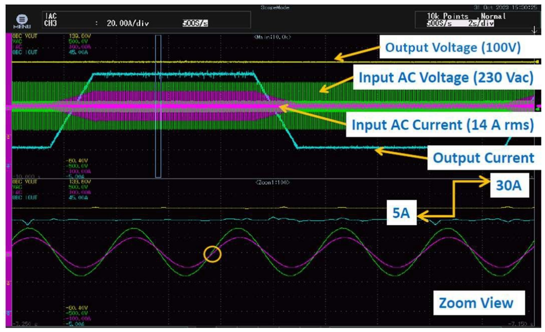
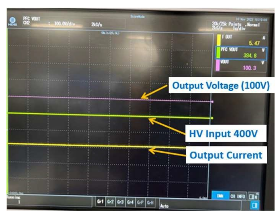
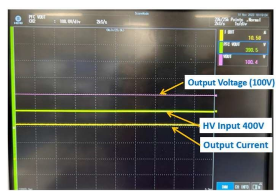


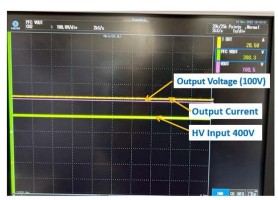
Fig. 6. Experimental results for the Case-A



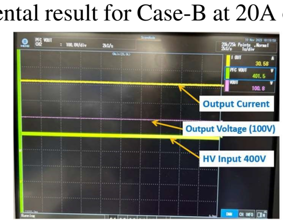
(**a**) Experimental result for Case-B at 5A output current



(**b**) Experimental result for Case-B at 10A output current



(**c**) Experimental result for Case-B at 20A output current



(**d**) Experimental result for Case-B at 30A output current

Fig. 7

Similarly, the experiments performed for Case-B to validate the proposed charging methodology at different charger output currents and the results are shown in Figures 7(a)-(d). The obtained results show excellent performance at HV input. In summary, extensive experiments have been performed for both cases, i.e., Case-A and Case-B. From the results analysis, it is observed that the developed charger and setup configuration can emulate the required charging strategy to validate the proposed methodology. Finally, the conclusions are presented in the next section.

5 Conclusions

This paper proposed a novel battery charging method for PFCHEV in an Indian scenario. Here, the battery can be charged from the CCS or other DC-fast charging stations or AC source. This method will save hydrogen on board and help increase the vehicle range. The proposed work's practical feasibility and effectiveness are validated through developed hardware and obtained experimental results. From the experimental result observations, it is found that the proposed charging methodology can be implanted in actual PFCHEV to increase the driving range of the vehicle by availing the facility of the charging station.

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