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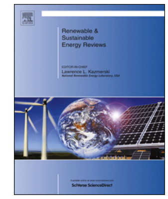

Contribution of Plug-in Hybrid Electric Vehicles in power system uncertainty management

Jamshid Aghaei [a,*], Ali Esmaeel Nezhad [b], Abdorreza Rabiee [c], Ehsan Rahimi [b]

[a] Departments of Electronics and Electrical Engineering, Shiraz University of Technology, Shiraz, Iran
[b] Young Researchers and Elite Club, Shiraz Branch, Islamic Azad University, Shiraz, Iran
[c] Department of Electrical Engineering, Faculty of Engineering and Technology, Shahrekord University, Rahbar Blvd., P. O. Box 115, Shahrekord, Iran

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ABSTRACT

Electric vehicles, including both PEVs and PHEVs have been recently interested to a large extent in global markets due to their capabilities. These plug-in vehicles are able to absorb/inject power from/to the electric grid that turns them into an interesting solution for the power systems. However, large numbers of such plug-in vehicles can be a threaten to power systems. In this regard, it seems necessary to investigate the problems caused by the uncertain driving nature of such electric vehicles. On the other hand, the opportunities provided by the presence of a large fleet of plug-in vehicles as mobile storage/load should be discussed. For this end, this paper reviews the challanges and the problems caused by charging/discharging of PHEV/PEVs in large numbers and investigates their capabilities as a solution to integrate the RESs and demand response programs in power systems.

Contents

Abbreviations: AER, All-Electric Range; CAES, Compressed Air Energy Storage; BFS, Breadth-First-Search; CARB, California Air Resource Board; CCP, Chance-Constrained Programming; CL, Charging Level; CO_2, Carbon dioxide; CPC, Contracted Power Capacity; CS, Charge-Sustaining; DG, Distributed Generation; DP, Dynamic Programming; DRP, Demand Response Program; DRXO, Demand Response eXchange Operator; DSM, Demand Side Management; DT, Day-ahead Tariff; EA, Evolutionary Algorithm; ECF, Electric Charging Facilities; ESS, Energy Storage System; EV, Electric Vehicle; FC, Fuel Cell; G2V, Grid to Vehicle; GA, Genetic Algorithm; GHG, Greenhouse Gas; GV, Gridable Vehicles; HEV, Hybrid Electric Vehicle; ISO, Independent System Operator; IEMS, Intelligent Energy Management System; LA, Load Aggregator; LP, Linear Programming; LV, Low Voltage; MAS, Multi-Agent System; NHTS, National Household Travel Surveys; NO_X, Nitrogen oxides; PG&E, Pacific Gas & Electric; PDF, Probability Distribution Function; PEN, Proportional Energy Needed; PEV, Plug-in Electric Vehicles; PFC, Power Factor Correction; PHEVs, Plug-in Hybrid Electric Vehicle; PSO, Particle Swarm Optimization; PV, Photovoltaic; QP, Quadratic Programming; RES, Renewable Energy Sources; SCE, Southern California Edison; SO_2, Sulphur dioxide; SOC, State Of Charge; TSO, Transmission System Operator; UC, Unit Commitment; V2G, Vehicle to Grid; VC, Vehicle Controller; VPP, Virtual Power Plant; WT, Wind Turbine

* Correspondence to: Department of Electrical and Electronics Engineering, Shiraz University of Technology, Room no. 99, Modarres Blvd., Shiraz 71557-13957, Iran.
E-mail address: aghaei@sutech.ac.ir (J. Aghaei).

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1. Introduction

During the past decades, the petroleum reserve has been exhausted dramatically, while the need for energy has increased. Moreover, the global warming and climate change have made the conditions more critical. These issues in addition to emissions caused by using fossil fuels in populated areas cause the transportation sector, which is one of the main sources of emission to find an alternative energy source to meet the energy demand in the future [1]. It is predicted that if the current conditions on oil discovery and consumption proceed, the oil reserve will be exhausted by 2038 [2]. One way to get rid of these pollutants caused by burning fossil fuels, such as CO_2, SO_2 and NO_X, in such areas is to substitute conventional vehicles with electric ones, particularly PHEVs [3]. For instance, providing that all the electric energy needed for charging PHEVs is supplied from coal plants with the emission equals to 950–1200 g CO_2-eq/kwh, PHEVs' emissions are still less than conventional gasoline vehicles (325–365 g CO_2-eq/mile compared to 400–450 g CO_2-eq/mile) [4,5]. Ref. [4]. represents the potential long-term GHG emission effects of PHEVs using precise models of the U.S electric and transportation sectors and defining two sets of scenarios over 2010 to 2050 time horizon. On the other hand, because of the increasing fuel price which is due to several reasons, using EVs might be a good solution. EVs can reduce fossil fuel consumption and GHG emissions and also improve the energy security by shifting demand from the fossil fuel energy to RESs [6]. RES-based sources like WTs, FCs and PV systems would be appropriate alternatives to electric system grid. The EPRI's projected research in 2007 shows that if the electricity needed for charging PHEVs is supplied through wind power, well-to-wheels PHEV emissions will be lowered to 120 g CO_2-eq/mile [4]. From the environmental and economic aspects, wind energy is a free and clean, innovative, modular, intermittent energy that never finishes [7]. With more accessibility of RES-based energies, specifically wind energy, PHEVs are able to be charged through an electric grid with RES technology penetration. PHEVs are able to reduce the fuel consumption up to 70% compared to conventional vehicles [2]. However, PHEVs are yet to become a general vehicle. The most significant factor from the customer's viewpoint is the PHEVs' cost. Therefore, there should be incentives for PHEVs like in California [8]. In California, free installation of Electric Vehicle Service Equipment is offered by local government subsidies or company donations. Another incentive-based activity is offering lower charging cost during off-peak hours at PG&E and SCE. In addition, CARB gives about $5000 discount on PHEV purchase and free PHEV parking is offered throughout the state in addition to some other incentives presented to customers in California.

So far, many car manufactures have started producing PHEVs, such as [9–11]. PHEVs are a kind of hybrid electric vehicles that are able to absorb and store energy from the power grid to charge their batteries to move the vehicle. PHEV has approximately the same structure as customary HEVs available in the markets [12]. The conventional HEVs consume common liquid fuels producing required electricity onboard while a PHEV has the ability to connect to the electric grid via a plug to inject/absorb electric energy from/to the grid. All PHEVs' and HEVs' abilities to reduce the fossil fuel consumption have been accomplished through reducing the engine size and also utilizing switching flux motors and regenerative braking to recover a considerable amount of energy [13]. These capabilities of PHEVs have turned them into a powerful tool in the transportation and power system sections, because they can substitute fossil fuels with multi-source electric energy [14]. So, the fossil fuel-based transportation system is changing to access lower-cost, cleaner, and higher renewable energy by connecting PHEVs to the grid [15].

EVs have batteries with great capacity that are charged by the power grid. Therefore, some parking space must be considered to charge the PEV's and PHEVs' batteries in cities, that such places are known as parking lots. Beside the parking lots, some home charging facilities are accessible in the market for PHEVs. Hence, PHEVs can be fully charged in a parking lot or at home with ECF. The charging time at home would be longer than that of parking lots, because parking lots are equipped with fast charging utilities. In this regard, there are two charging facilities for PHEVs to be charged or discharged: single point charging and multi-point charging facility. The first one is located in residential places or parking areas which has low charging rate and it is suitable for normal or slow charging. The second one is located in places like gas stations called charging stations, appropriate for fast charging [16]. Parking lots are defined as places where vehicles are parked 2–8 h a day [17]. Despite the advantage of utilizing PHEVs, such as the ability to partially decrease emissions from urban areas, they also have some problems. From the grid-side viewpoint, a PHEV can be basically regarded as a load [18], but a large number of PHEVs when randomly connect to the power grid, will bring a severe challenge into electric power grid to both transmission and distribution systems in operation and management [19]. Additional electrical loads may affect the power system in the case of power losses and voltage deviation. The large number of PHEVs impose additional and undesirable peaks to distribution networks [20]. For instance, in Ref. [21], it is expressed that the large capacity of PHEVs has a significant influence on charging load of the electric grid. Ref. [22] declared that applying large number of PHEVs probably increases the demand peaks, reduces reserve margins, and increases prices. It is also claimed that if no measures are taken, PHEVs' uncontrolled behaviors on charging may cause negative effects on voltage control, power quality (harmonics and sub-harmonics), balancing supply and demand and also cause the protection relay' settings to be changed.

According to the above-mentioned discussions, it seems essential to review and investigate the impacts of PHEVs on the electric power system in distribution and transmission levels. Then, PHEVs' role in the DR program is discussed. Finally, the use of PHEVs in decreasing wind generation intermittency is well defined.

2. A review on different types of EVs

As the world population increases, the demand for more environmentally compatible and higher fuel economy vehicles increases. Therefore, automobile industries have to satisfy their customers' demands. As a result, they started working on AFVs including PEVs, HEVs, PHEVs and fuel-cell vehicles [23]. Here because of the faster growth of PHEVs in transportation sector and their impacts on the electric power system, PHEVs are mainly intended to be investigated and compared to other types.

2.1. Brief comparison of PEV, HEV and PHEV

Earlier than PHEV, PEV and HEV had been invented to overcome the problems regarding the fossil fuel consumption in the transportation sector. The first and the fundamental problem of PEVs is that the only source of energy is battery converting electrochemical energy to the electric energy needed for propulsion system. To eliminate this deficiency, HEVs have been produced. This type of electric vehicles has two or more sources of energy and two or more sources of power on-board vehicle. The energy might be battery pack, a flywheel, etc. and the power source can be an engine, a fuel cell, a battery or an ultracapacitor [23]. But the main problem of HEVs in comparison with PEVs is that the total energy used in HEVs with battery CS operation strategy is only provided by burning fossil fuels, mainly gasoline and diesel. Recently, PHEVs have been produced to cope with the previous mentioned problems of HEVs and PEVs. Accordingly, PHEVs seem to be the best option to be substituted with conventional vehicles.