Energy 118 (2017) 197–208

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

A flexible control strategy of plug-in electric vehicles operating in seven modes for smoothing load power curves in smart grid

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ARTICLE INFO

Article history:
Received 15 August 2016
Received in revised form
30 November 2016
Accepted 11 December 2016

Keywords:
Plug-in electric vehicles
Lithium-ion battery
Smart grid
Supervision strategy
Load power variance

ABSTRACT

Plug-in electric vehicles (PEVs) seem to be an interesting new electrical load for improving the reliability of smart grid. The purpose of this work is to investigate a supervision strategy based on regulated charging of PEVs in order to guarantee an optimized power management of the system and consequently a flatter power demand curve. The system mainly includes PEVs powered by a Lithium-ion battery ensuring the charging and discharging operations of these PEVs at home and a daily load power demanded by home appliances. The purpose of the considered strategy is to detect the connection status of each PEV and to establish the priority order between these PEVs with certain flexibility which results in managing the PEVs through seven operating modes. The response of the control algorithm enables to ensure the power flow exchange between the PEVs and the electrical grid, especially at rush hours, and to minimize load power variance aiming to achieve the smoothness for the power demand curve and to reduce the stress of the electrical grid. The simulation results are presented in order to illustrate the efficiency of this power control approach.

1. Introduction

Up-to-date, the world has undergone a challenge in terms of providing electricity and ensuring global energy requirements. The challenge is mainly due to the shortage of primary energy resources from conventional fossil fuels like natural gas, coal and oil [1]. As a result, there is a great tendency to integrate the renewable energy resources and the use of plug-in electric vehicles (PEVs) on the smart grid in order to minimize reliance on conventional energy resources, satisfy the energy demands and consequently decreasing concerns related to global warming effects as well as the ones related to energy crisis [2–5].

The excessive electricity consumption causes intense surges in demand during peak hour which can cause undesirable impacts and harm the stability of the existing network. That's why; some researchers are working on ways to minimize load power variance by using renewable energy sources. In Ref. [6], a stochastic multi-objective daily volt/var control based on hydro-turbine, fuel cell, wind turbine, and photovoltaic power plants are investigated. A study in Ref. [7] has developed a new control strategy that involves wind and photovoltaic generation subsystems. This strategy has been suggested with the objective of load power demand satisfaction, storage and grid constraints verification in order to avoid blackout. These methods have presented good solutions to reduce load power variance and enhance power electrical system quality. However, the common disadvantage of this renewable distributed generation is their intermittent and unstable production due to their dependence on weather change and climatic fluctuation. Currently, power systems supervision has been changing leading to accomplish renewable energies gaps and use new paradigms in the functioning and improvement of power systems.

Plug-in Electric Vehicles (PEVs) as an emerging new electrical load and a significant approach on smart grid, have attracted more attention worldwide and have appeared as future solution towards solving problems for the energy management owing to their mobility and power storage properties [8,9].

In that, smart grid as a suitable concept has a potential to improve grid modernization for making it more able to address future need, more efficient and accommodating [10]. Some researchers are interesting in smart meters, electricity storage technologies, and electrical local smart grids in which they develop the design of coherent smart energy systems as an integrated part of achieving future 100% renewable energy and transport solutions [11,12]. Ref. [13] has presented the interest profits, risks and a

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http://dx.doi.org/10.1016/j.energy.2016.12.039

challenge concerned in smart grid and has insisted on the impact of the actual smart grid modernization for potential and reliable energy generation. Indeed, the need for new flexible electric power with quality improvement leads to the development of the bidirectional flow of electricity and information [14]. Communications flow is used to collect data supplied by meters and sensors that can be used to permit both consumers and utilities to reply to the grid status [15]. In this context, these PEVs are equipped by batteries which can operate as a load on the grid known as grid-to-vehicle (G2V) concept or as a power source known as vehicle-to-grid (V2G) concept [16,17]. It has been proved that the V2G technology can describe an interactive relationship between PEVs and the power grid [18,19], help to realize the balance between production and consumption of power grid, participate in frequency regulation [20], so as to flatten the variation of the load power profiles [21], reduce cost [22] and integrate renewable energy sources [23]. From these interesting benefits, various researches have been carried out the PEVs and their integration into the grid. Ref. [24] discusses the impact of PEVs and V2G technology to integrate a highly level of wind generation without excess on electricity production as well as greatly to minimize national CO2 emissions. Ref. [25] describes the main challenge of renewable energy strategies to include the transportation field in these strategies for sustainable development purpose and discusses the potential solutions for this challenge in Denmark case. Authors in Ref. [26] have concentrated on the notions of G2V concept and V2G technology, their economic benefits depending on the charging strategies of PEVs (coordinated/uncoordinated charging) and their effects on power distribution networks. Others in Ref. [27] are working on the optimal scheduling of charging/discharging behavior of electrics vehicles. They are adjusting the PEVs power and are proposing a locally optimal scheduling scheme.

Researchers in Ref. [28] are working on the performance of batteries for PEVs. They have exanimate the recent battery technologies for PEV and the most important parameters to maximize the effectiveness and competitiveness of PEV battery on short and long term. Ref. [29] has presented an estimated sample model-based health management of Lithium-ion batteries for electrified vehicles to maintain the battery lifecycle. A study in Ref. [30] has explained new dynamic model at battery swapping station for electric vehicles in electricity market.

Within the smart grid concept, much studies has been concentrated on the active participation of demand-side response, household electricity use and smart homes in terms of their structures, components, and benefits [31–33]. An overview of services offered by smart home and reveals key barriers to smart home adoption was carried out in Ref. [34]. Authors in Ref. [35] focus on the prediction of the next day energy consumption for smart homes. Others in Ref. [36] proposed a home energy management system to manage household energy consumption aiming to keep the customer comfort at a good condition. Moreover, there are several studies aiming to reduce load power variance. For instance, an energy retailer scheme that permits investigating demand response in electricity supply is presented in Ref. [37] in order to achieve load minimizing based on price elasticity using Power Systems Computer Aided Design (PSCAD). An improvement of the load variance in household smart micro-grid using charging profiles of plug-in hybrid electric vehicles driven by the residents was explored in Ref. [38].

Although these considered studies have elaborated different aspects for PEVs charge scheduling, energy loss minimization and consequently load power variance enhancing, however, it is notable that there is not enough flexibility either in PEV time connection, or in energy demand as well in duration of charging.

In this paper, a flexible control strategy of PEV operating in seven modes is proposed. The aim is to satisfy the energy dispatching between PEVs and power grid and to minimize the load power variance. For that, an appropriate algorithm must be achieved to generate the optimal required powers and avoid the high electricity demand in peak hours. In fact, the main contribution of this work is to monitor the system under different operation modes of activation according to the following constraints: (i) the daily load demand of the household appliances, (ii) the connection time of the each PEV, (iii) the priority order and the state of charge (SOC) value of each battery.

The algorithm presented is flexible and applicable for any house equipped with two PEVs which could provide grid support by injection or absorption of their optimal reference powers when charging slot time that are available at home.

The flexibility of this approach is shown in PEV time connection and their charge/discharge duration. Indeed, the bidirectional energy flow of vehicle to home (V2H) provides greater flexibility to control the PEV battery energy which is one of the recent technologies. It can be considered not only as an electric load but also as a storage system and thus a supplier of electrical demand at home appliances. The focus of this considered strategy is thus, firstly, the detection of the presence of each PEV taking into account the priority selection of PEV owner chosen charging time period, and secondly, the availability of these PEVs to switch between many power flow feasibilities according to seven operating modes with a flexibility degree in order to achieve a flatter daily power demand curve.

The paper is structured as follows: section 2 shows the description of the studied system and the modeling of the battery as an important electrical part in exchanging power for each PEV. Section 3 details the control of PEV power generation. In section 4, the power control algorithm applied to the studied PEVs taking into account their connection status to the grid will be described. A flexible strategy is investigated to show the impact of this regulated charging on minimizing load power variance and flattening consequently the daily power demand curve. The simulation results and the conclusion of this work are developed in sections 5 and 6, respectively.

2. System description and modeling

2.1. System description

The aim of this paper is to point out the high power of PEVs which could provide significant flexibility in their connection time and duration of charging when they are parked at home and to demonstrate the appropriate merits of V2G technology. As shown in Fig. 1, the studied home is equipped by AC powered devices, DC powered devices associated to DC/AC power converters to connect these load to the AC power grid and PEVs with their bidirectional chargers.

Each PEV includes a Li-ion battery pack, an inductive filter L, a bidirectional DC/DC converter, a DC link voltage bus, a bidirectional DC/AC converter and a line which is represented as an RL filter.

The direction of the current is the criterion to define the charge or discharge phase of the battery. Positive battery current determines the discharging operation and negative battery current determine the charging process. The L filter participates into the chopper operation and smoothes the charge and discharge current ripples. This inductor filter and the buck-boost DC/DC converter are used to ensure the possibility of bidirectional power flow exchange (charge/discharge) and to adjust the voltage levels between the battery pack and the DC bus. Therefore, the DC/DC converter aims to adapt the battery output voltage to the appropriate inverter input voltage. The bidirectional DC/AC converter which is