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PV powered smart charging station for PHEVs

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ABSTRACT

A huge inrush of PHEVs is envisioned in the future. There is a growing risk that, this proliferation in the number of PHEVs will trigger extreme surges in demand while charging them during rush hours. To mitigate this impact, a smart charging station is proposed in which the charging of the PHEVs is controlled in such a way that the impact of charging during peak load period is not felt on the grid. The power needed to charge the plug in hybrids comes from grid-connected photovoltaic generation or the utility or both. The three way interaction between the PV, PHEVs and the grid ensures optimal usage of available power, charging time and grid stability. The system designed to achieve the desired objective consists of a photovoltaic system, DC/DC boost converter, DC/AC bi-directional converter and DC/DC buck converter. The output of DC/DC boost converter and input of DC/AC bi-directional converter share a common DC link. A unique control strategy based on DC link voltage sensing is proposed for the above system for efficient transfer of energy.

1. Introduction

The growing global awareness for a pollution free environment, will lead to an increase in the number of PHEVs in the near future. This triggers the need for charging stations that can satisfy the requirements for a significant amount of power needed to charge the PHEVs. The proliferation of these PHEVs will add stress to the already overloaded U.S grid creating new challenges for the distribution network. Though it is always advantageous to charge the EV's during night time there will be considerable PHEV load during the day and even during the hours of peak demand. Transmission and distribution systems can be upgraded to meet the peak demand but this may result in capacity surplus during normal operating conditions. There is also a potential risk of night-charging challenge as the TOU (time-of-use) pricing is designed to discourage charging during the daytime. This would overload the distribution transformers which are otherwise designed to cool overnight. Though installing transformers with higher power rating would solve the problem, it is a rather expensive option. Hence, it's time to develop charging station infrastructure coupled with smart charging strategies which can reduce the stress imposed on the grid. One way is to use renewable energy resources to charge the PHEVs. Photovoltaic systems would be the best choice among the available options as they can be made dispatchable by employing external storage units.

As per the National household travel survey vehicles are parked for at least 5 h in a workplace environment [1]. Hence these places are favorable for developing charging station infrastructure but this would lead to serious overloading issues at the distribution level. Since upgrading of transformers is an expensive option for the utilities, this issue needs close attention as the PHEV penetration increases. Several papers have been published to address the overloading of distribution transformers while charging the PHEVs [2–4]. Nevertheless, not much study has been reported to be tightly related to the case of reducing the loading on distribution transformers using a photovoltaic system. Though few papers exist in the literature, they are mostly confined to residential distribution networks [5–7]. The present work proposes a PV powered charging station for PHEVs in a workplace environment to reduce the stress imposed on the distribution transformers.

Large-scale deployment of photovoltaic chargers in a parking lot is analyzed in Ref. [8]. PV parking lot charging and other business models to charge EVs with solar energy are discussed in Ref. [9]. Economics of PV powered workplace charging station has been studied in Refs. [10,11]. The analysis shows the feasibility of a PV based workplace parking garage with benefits to the vehicle owner as compared to home charging, such that the garage owner will get the payback of installations and maintenance cost and profit within the lifetime of the PV panels. According to Ref. [11] integrating a solar collector into a parking lot would result in a much more rapid pay-back-period, encouraging widespread installation of solar

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capacity. Ref. [12] describes how smart control strategies can help EVs and PV to integrate with the present electricity systems. Co-benefits of large scale deployment of PHEVs and PV systems have been studied in Ref. [13]. The study concludes that PV provides a potential source of mid-day generation capacity for PHEVs, while PHEVs provide a dispatchable load for low value or otherwise unusable PV generation during periods of low demand (particularly in the spring). A 2.1 kW photovoltaic charging station integrated with the utility at Santa Monica is described in Ref. [14].

In most of the cases AC charging is employed because AC system has been used for years and there are well developed standards and technologies. DC charging on the other hand increases the overall efficiency by reducing the number of power conversion stages and also offers the advantage of fast charging [15–17]. Refs. [18,19] provide a proof of concept for this approach, demonstrating the safety and viability of this charging scheme. It also makes it convenient to integrate distributed renewable power generations such as wind, PV, fuel cells and other energy storage devices using the DC distribution bus. Several DC charging station architectures have been proposed by the researchers [20,21]. In case of Ref. [17] the control of the individual electric vehicle charging processes is decentralized, while a separate central control deals with the power transfer from the AC grid to the DC link. The authors conclude that DC fast charging of multiple EVs is possible but the impact of fast charging on the grid and ways to eliminate or reduce the stress on the grid are not discussed. As shown in Fig. 1 PHEVs are directly connected to the DC link by employing a DC/DC buck converter. The proposed architecture is an effective solution for charging PHEVs using a photovoltaic system. Ref. [22] reports a parking structure built at the University of South Florida for study of PV based PEV charging using DC power distribution system.

Design optimization of the PHEV charging station with the battery storage unit and renewable energy sources has been proposed in Ref. [23]. Optimized schedule of charging PHEVs based on the uncertain availability of renewable energy resources is proposed by the authors. The optimization approach reduces the price of electricity for charging PHEVs even under poor forecasting and high uncertainties of PV and wind. Ref. [24] describes the concept of delayed charging to reduce the loading on distributions transformers. An intelligent energy management system is proposed in Ref. [25]. The energy management system allocates power to the vehicle battery chargers through real time monitoring, to ensure optimal usage of available power, charging time and grid stability. None of the papers reviewed so far describe the control and architecture of the power electronic interface needed to implement the energy management system.

In Ref. [21] the authors proposed a plug-in hybrid electric vehicle (PHEV) solar carport charging station concept featuring a multi-port power electronic interface connecting photovoltaic modules, PHEVs, and the power grid. Ref [15] proposes a solar carport with direct DC/DC interface to increase the overall efficiency. Though both the above papers deal with energy conversion systems featuring three-way energy flow involving the power grid, PV modules, and plug-in hybrid vehicles, the paper did not implement smart charging techniques to reduce the impact on distribution transformers.

The concept of DC bus signaling (DBS) has been employed to supply power to the DC loads. DBS induces dc bus voltage level changes to realize the communications between different source/storage interface converters [26,27]. Though DBS is a novel idea it does not take the change in sun's insolation into consideration which in turn impacts the DC bus voltage level. In Ref. [28] the dc link voltage level changes due to the change in sun's insolation but the feasibility of the proposed control strategy was not validated experimentally. This paper validates the practical feasibility of the proposed control strategy in Ref. [28] through experimental results using a laboratory prototype. The change in irradiation of the sun induces changes in the DC link voltage level. Based on the change in DC link voltage level and the loading condition of the distribution transformer the operation of the charging station can be categorized into 4 modes: grid-connected rectification, PV charging and grid-connected rectification, PV charging and grid-connected inversion.

2. Significance of the proposed charging station

It is predicted that there will be one million plug-in hybrid electric vehicles on the road by the year 2015 [29,30]. This will add extra load to the already overloaded U.S grid. Extensive research on design and implementation of a smarter grid is going to play an important role in

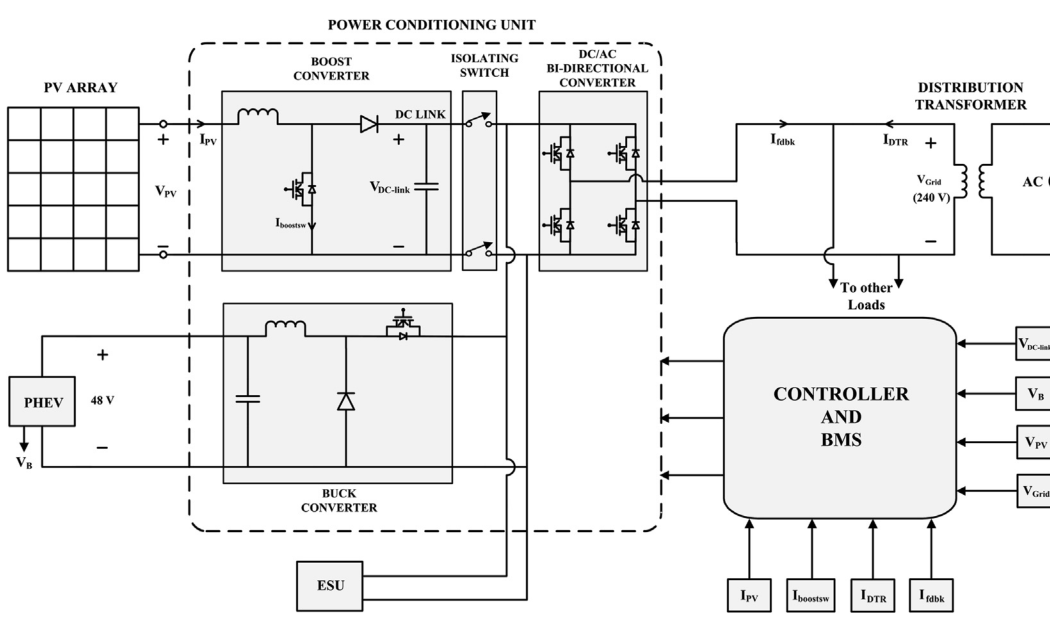

Fig. 1. Detailed block diagram showing the PCU and controller.