

Hybrid model of Photovoltaic Power Plant for Electric Vehicle Charging System

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Abstract

This paper presents an efficient bidirectional-dc converter system for electric vehicle [EV] charging, which is placed between the high-voltage dc bus of photovoltaic [PV] inverter and the EV battery. The system partially alleviates feeder overloading by providing fast charging of EV battery from the PV system. In addition, it reduces the rate of change of inverter output power to a significant low value. The paper also addresses sizing of the charger and energy storage based on the PV system ratings. Analysis suggests that small amounts of energy storage can accomplish large reductions in output power ramp rate. Simulation results are shown for a 10 kW dc-dc charging system, which works on bidirectional, four-phase, zero-voltage-switching converter with high efficiency.

Index: Bidirectional dc-dc converter, electric vehicle [EV], inverter battery.

I. INTRODUCTION

Our concerns over climate, energy, security, and rising fuel prices have lead much growing interest in generation and utilization of electric power from renewable resources. However, renewable resources, such as photovoltaic (PV) power systems are highly intermittent and variability in output power, especially in locations with frequent cloudy weather, which lead to sudden, significant fluctuations in PV based output power systems. The response time of large utility and auxiliary diesel power generators can be on the order of tens of seconds or longer, which may not be fast enough to compensate for the variability of these renewable sources. The new efforts and approaches, like plug-in vehicles on the electric power grid have also been considered. Particularly, the vehicle-to-grid (V2G) concept is based on the idea of utilizing a large fleet of electric vehicles as an energy storage resource. When this is implemented at a large scale, challenges lie in coordinating large numbers of distributed energy storage resources to absorb excess supply or meet excess demand, and also retaining the basic battery

charging functions and adverse effects on battery life. The concept of integrating energy storage or EV charging in a distributed manner, e.g. within a PV power system can be simpler and easier to deploy and demonstrate. Many residential, commercial or utility-scale PV systems typically contain a high-voltage dc bus between the maximum power point tracker and the inverter, as shown in Fig. 1. The dc bus provides a convenient point for integration of energy storage or dc-dc vehicle chargers. PV systems with battery backup have been proposed without and with integration of vehicles. However, the grid support provided by the batteries in these systems is either not mentioned or is on a long time scale, such as supplementing PV output at night. Providing such a service requires very significant energy storage capacity and can result in significant swings in battery state of charge, thereby compromising battery life.

This paper is based on mitigation of solar irradiance intermittency at short time scales.

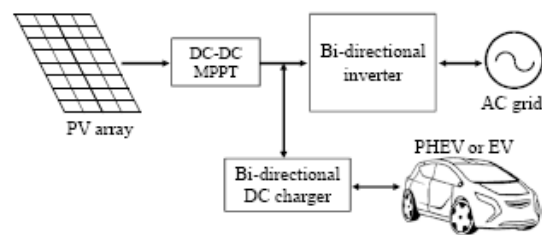


Fig 1:Block diagram of an electric vehicle (EV) dc charger integrated with a PV power system.

A typical operation of the system is shown in Fig.1. The inverter controls the dc -bus voltage by exporting power to the grid and commanding the charger to sink or source power to or from the vehicle battery. During sunny conditions, the charger siphons off some of the PV current to charge the vehicle battery, thereby putting no additional load on grid system. If

the clouds pass over the array, the inverter commands the charger to decrease the current to the battery or even source current from the battery in order to limit the variability of the inverter output power. Instead, a much smaller storage resource can be used to provide other grid support functions at shorter time scales. The effects of passing clouds can be compensated by sourcing or sinking current to or from the battery for short periods of time. The result is a much smoother inverter output power, free of large, fast transients. From a grid operator's perspective, smoother power output translates to reduced spinning reserve requirements and greater grid stability, especially on grids with high penetrations of renewable energy. Furthermore, considering the goal of EV charging directly from a PV source, dc-dc charging system as shown in Fig. 1 are more efficient and less costlier than the conventional ac-dc chargers.

II. SYSTEM DESCRIPTION

The grid architecture uses a regulated dc-link voltage with dc-dc converters to interface numerous PV strings to the DC-bus, allowing each string to operate at its own maximum power point (MPP). The constant dc-link voltage of PV system is naturally extended to include bidirectional dc-dc converters that interface with PHEV batteries Figure 2. Bidirectional dc-dc converters allow the use of vehicle batteries as a modest energy-storage resource to provide some grid-side services via the grid-interactive inverter. This architecture offer a number of attractive attributes from the perspective of both the utility and the end-user, including improved capacity factor of the PV system, elimination of fluctuations in PV power plant output, simplified and highly responsive system control, and integration of level-3 vehicle charging without presenting additional load to the grid. PV grid-integration energy-storage functions are obtained at no additional cost to the grid operator, or to the vehicle owners. The additional cost of dc-dc battery converters in the PV plant is relatively small.

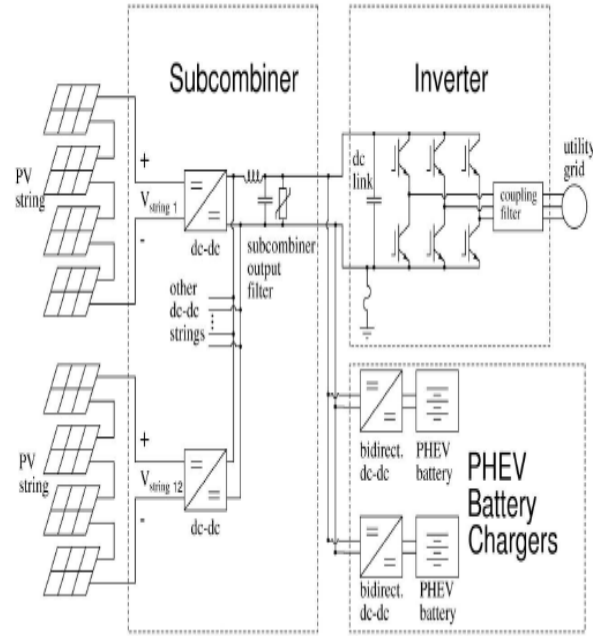


Fig2: Grid-interactive inverter system with constant dc-link voltage, and battery charger banks.

III. BIDIRECTIONAL DC-DC CHARGER

The 10-kW charger is designed and constructed based on four-phase, current-controlled, and bidirectional synchronous buck topology as shown in Fig. 3. Zero voltage switching quasi square-wave (ZVS-QSW) operation is maintained across all operating points by allowing resonant transitions between the inductor and the switched-node capacitance. MOSFETs operated at 30 kHz are used as the switching devices. The high voltage side connects to the 575 V DC bus of the GRID inverter; the lower voltage side connects to the battery. The modules are operated in a multi-phase phase-shifted manner; so that the individual module inductor currents cancel each other out, resulting in very low output current ripple. Each module operates as a buck converter from the input (DC bus voltage) to the output (battery voltage), or as a boost converter from the output (battery) to the input (DC bus). In each module, the inductor current, the average of which is the same as the battery current, is sensed by a Hall-effect sensor, and sampled multiple times per switching period through an A/D converter. The current control is achieved digitally, with a step response time of approximately 1ms, which is the same in charging mode, discharging mode, or when

transitioning between charging and discharging modes.

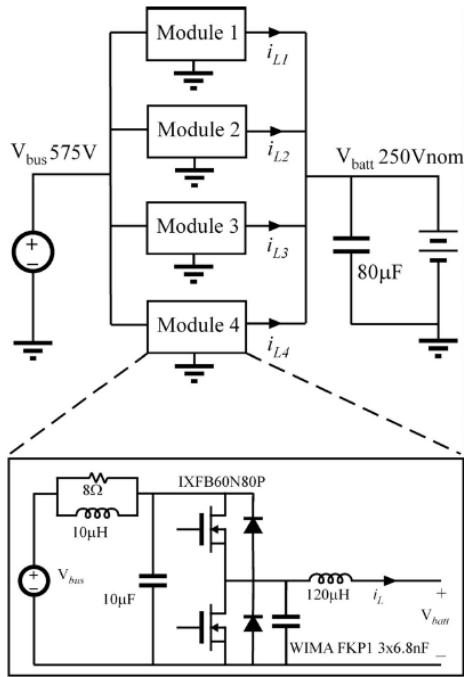


Fig3:Schematic diagram of charger and module

In each 2.5-kW module, the resonant components consist of a 120- μ H inductor and three 6.8-nF capacitors connected in parallel at the switch node between the power MOSFETs. Each module is controlled by a dsPIC microcontroller that implements a feedback loop around the average inductor current designed for a crossover frequency of 1 kHz and phase margin of 65°, utilizing a discrete-time PI compensator. The four module microcontrollers are synchronized and phase shifted by a central microcontroller in order to cancel input and output ripples. The central controller is also responsible for communicating with the inverter and monitoring the SOC of the battery.

Table 1: Bidirectional DC-DC Charger Specifications

Parameter	Specification
Input (DC Bus) Voltage	$V_{DC} = 575\text{V} \pm 75\text{ V}$
Output (Battery) Voltage	$200\text{ V} < V_{bat} < 350\text{ V}$
Output (Battery) Current	$-40\text{ A} < I_{bat} < +40\text{ A}$
Output (Battery) Power	$10\text{ kW} < P_{bat} < +10\text{ kW}$

A. Control System

The inverter's system controller is designed with the following control objectives:

- Minimize sudden step decreases of power injected into the point of common coupling with the utility
- Maximize power exported to the utility
- Charge the PHEV batteries to a nominal set-point, without allowing their state of charge (SOC) to decrease below some threshold during transients.

The relative priorities of these objectives become important for highly intermittent irradiance profiles, where the PV array is not allowed to be curtailed (achieved by moving it off its MPP). Summing currents at the dc-link node of the inverter in Figure 2 is one way of deriving the implicit requirements of the PHEV charging system. The resulting current balance requires that destabilizing components of the PV output current are actively cancelled by the PHEV charger. The slower process of charging the PHEV batteries continues as permitted by the average irradiance. Any remaining PV energy not needed for battery charging can be exported to the utility without inducing fast disruptive transients at the inverter point of common coupling to the power distribution system.

B. Loss Budget and Inductor Design

The Infineon IPW90R120C3 was chosen as a switching device because of its relatively low on-resistance and minimal switching losses in ZVS operation. At full output power and duty cycle equal to 0.5, the MOSFETs are expected to dissipate approximately 30-W per module. The second largest component of the power stage design is the inductor. In order to maintain ZVS operation at all operating points, the inductor current must have a peak-to-peak ripple that is greater than twice the maximum dc current. Each module is designed to output a nominal dc current of 10 A, and a maximum of 12 A. To support ZVS-QSW operation, the peak-to-peak inductor current ripple is designed to be 38 A. With such high ac and dc currents, the inductor requires careful design to avoid saturation and minimize copper losses due to proximity effects. The inductor

The results are shown below:

Charge and Discharge is happening at 0 to 0.5 sec and 0.5 to 1 sec respectively.

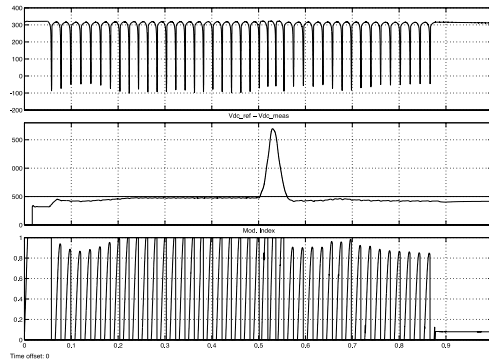


Fig.6: Charging and discharging happening in single run the solar fluctuation is not affected and the V_{dc} voltage is stable. The sudden peak of voltage is happening due to battery switching operation.

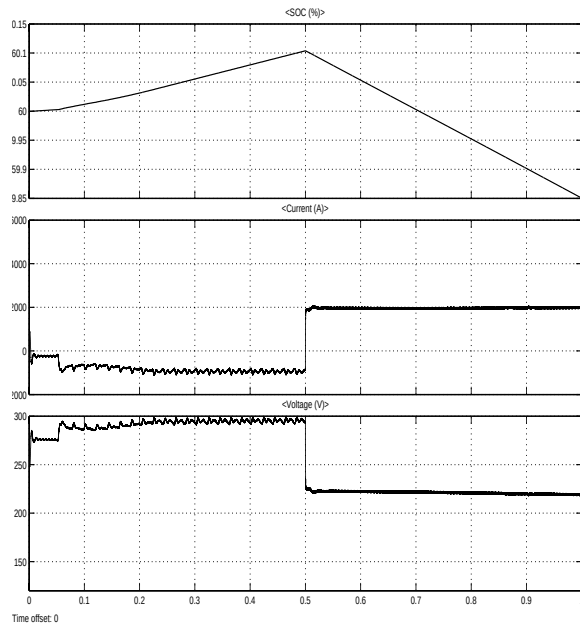


Fig7: Charging and discharging operation is happening at the same time the SOC is increasing from 60 % and after 0.5 sec it is decreasing from 60.1% to 59.85 %. So the charging current is negative at the charging time and discharging operation gives positive current.

Lab. Experimental results

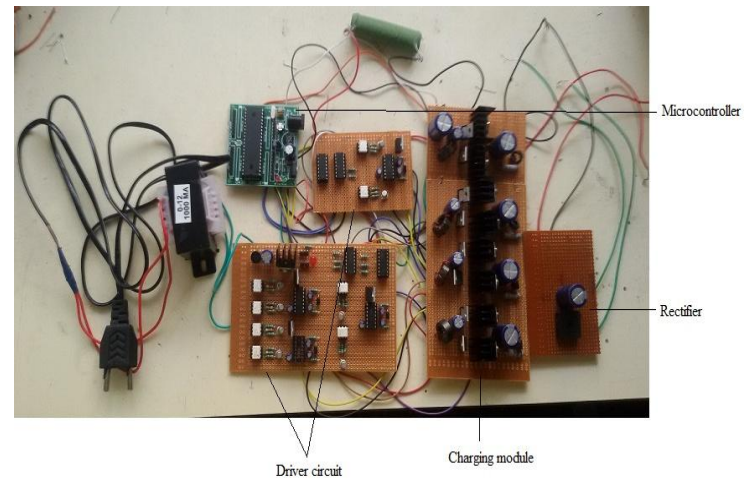


Fig8:Proposed bidirectional dc-dc converter prototype hardware.

IV. CONCLUSIONS

This paper addresses integration of an EV dc charging system with a PV power system. System analysis and experimental results indicate that a dc-dc charger inserted between an EV and a dc bus voltage of a PV system can improve grid integration of PV systems by reducing the ramp rate of the PV inverter output power, while simultaneously offering fast EV battery charging with high efficiency directly from the PV system. The simulation results analysis suggests that small amounts of energy storage can accomplish large reductions in output power slew rate. A prototype of 10-kW, 575-to-250-V bidirectional dc-dc charger can be constructed to validate the PV/EV charger concept in combination with a 10-kWh, LiFePO₄ EV battery installed in a motor car like, Toyota Prius and the other vehicles. The dc-dc charger is based on a four-phase zero-voltage-switching quasi-square-wave synchronous buck converter operating at 30 kHz. It can be demonstrated by Lab. experiments that the dc-dc charger with PI compensated average current control is capable of implementing the filtering technique with high efficiency (up to 98%) across a wide range of operating points.

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