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Performance Enhancement of Battery Charger for Electric Vehicles Using Resonant Controllers

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Abstract

This paper proposes a current proportional-resonant control strategy to reduce second-order harmonic of electric vehicle battery charger. Using the PR controller, the charger reference tracking performance can be enhanced. The steady-state errors in single-phase charging system can be reduced effectively. The PR controller stability influence factors including proportion coefficient, resonant coefficient and cutoff frequency are discussed in the paper. Finally, simulation results achieved on a 3.3kW charging model prove the proposed strategy effectively minimizes the low-order frequency ripple in grid-interfaced converter.

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Keywords: Electric vehicle charger, proportional-resonant controller, ripple reduction

1. Introduction

The development of electric vehicles (EVs) battery charger system has received much more attention in research communities, auto-manufacturers and government [1-4]. EV charger is a kind of power converter which performs electric energy from the grid to energy storage device. It is an essential element between the grid and EVs battery pack. Furthermore, the battery charger is highly non-linear load in power system. It presents a potential problem to grid in forms of poor power factor and excessive harmonic current injection. It imposes a requirement on the battery charger not only charger the battery efficiently but also follow IEEE 1547 standard.

A variety of circuit topologies have been developed for EV battery charger. The two-stage ac/dc and dc/dc power conversion architectures is considered as suitable for EV battery charger. However, the single phase ac/dc converter provides inherent low frequency ripple in grid current. A large dc link capacitor is used to filter the input power fluctuation. Unfortunately, the electrolytic capacitor cannot be used for EV application due to its short lifetime. A film capacitor is selected to replace electrolytic capacitor, which results in an increasing of the size and cost of the converter device. High power density is crucial for on-board battery charger of EV due to the space constraints. With the development of wide bandgap power electronic switches, Silicon Carbide (SiC) and Gallium Nitride (GaN) are used in EV battery charger application gradually, which can improve the system switching frequency effectively. However, the ripple energy at twice the grid frequency cannot be reduced by increasing the switching frequency.

Typical EV battery charger consist of an input filter, an EMI filter, a bidirectional rectifier, a power factor correction circuit and isolated dc/dc converter. The general block diagram of an EV battery charger described above can be seen in Fig.1.

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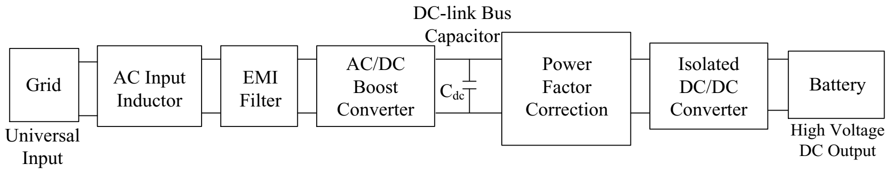

Fig.1. Typical block diagram of an EV battery charger.

Regarding single phase battery-charging system, the battery is subject to current ripple which is two times of the line frequency. Some Lithium Iron Phosphate battery test results indicate the low frequency current ripple such as double frequency ripple cause noticeable battery temperature increasing. The performance of Lithium ion battery do not deteriorate significantly with high frequency harmonic current. Therefore, further investigation is still needed to research about the low frequency current ripple effect based on repetitive cycle tests over a long term.

The bidirectional rectifier can boost the grid voltage and regulate it to dc link. The conventional ac/dc boost converters use a simple linear proportional-integral (PI) controller, which includes steady-state error in single phase system. The proportional-resonant (PR) controller is proposed in this paper to improve the EV battery charger performance.

The paper is organized as follows: the EV grid-connected charger system configuration is briefly recalled in Section 2. In Section 3 the single phase rectifier passive components are designed. Based on the circuit parameters, the PR controller impact on ripple energy at twice line frequency is analyzed and investigated in Section 4. Section 5 shows the simulation results to verify the proposed PR control strategy. The conclusion is presented in Section 6.

2. EV battery charger system configuration

The topology of the single phase PWM rectifier is described in Fig.2. u_{ac} and i_{ac} represent the grid voltage and current, respectively. U_{dc} and I_{dc} represent the load voltage and current. The unipolar modulation method is shown in Fig.3.

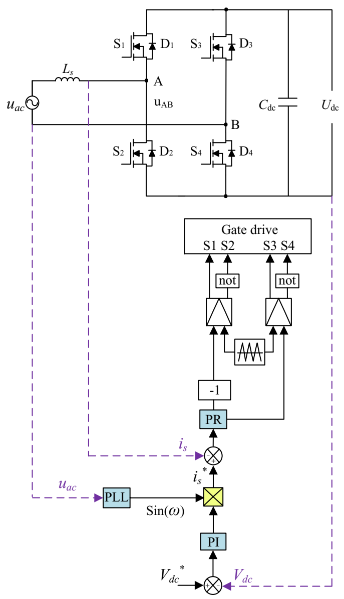

Fig.2. Single-phase PWM rectifier topology structure.

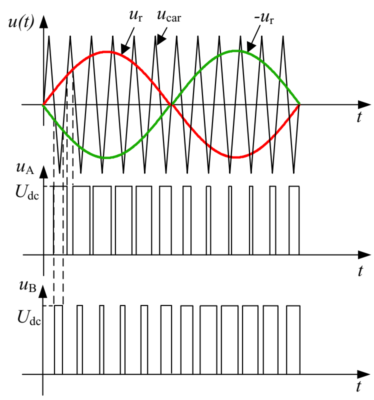

Fig.3. Unipolar modulation.

The vector relationship between grid side electromotive force E, grid voltage V, input inductor voltage V_L and grid current I_{ac} can be seen in Fig.4.