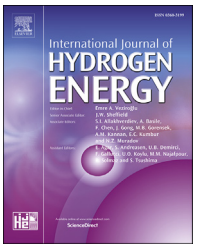
INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2017) 1–7

Available online at www.sciencedirect.com

ScienceDirect

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



Dead-beat instantaneous power control for off-board charger of electric vehicle for V2G application

Ran Jiao[*], *Jie Zhu, Longfei Ma, Yutong Zhao, Baoqun Zhang, Yifeng Ding, Cheng Gong, Shuo Yang*

State Grid Beijing Power Research Institute, Fengtai District, Beijing, China

ARTICLE INFO

Article history:
Received 13 March 2017
Received in revised form
1 April 2017
Accepted 18 April 2017
Available online xxx

Keywords:
V2G
Off-board charger
Instantaneous power
Dead-beat control component

ABSTRACT

Dead-beat instantaneous power control strategy for electric vehicle off-board V2G charger is presented in this paper, to suppress harmonic pollution to power grid and realize bi-directional flow of electric energy. The charger consists of three-phase voltage source PWM grid-side converter and bi-directional dc/dc converter. A double closed-loop for three-phase voltage source PWM grid-side converter is designed firstly. And the outer voltage loop is used to keep dc bus voltage constant. The expected switching voltage components are achieved by substituting predicted instantaneous power with its instruction value, to form the inner dead-beat instantaneous power loop. Then a voltage–current double closed-loop for bi-directional dc/dc converter is proposed to implement two-stage charging, combining with constant-current charging and constant-voltage charging. Finally, the effectiveness and feasibility of the proposed control strategy are verified on the power-hardware-in-loop-simulation platform.

Introduction

At present, the problems of energy shortage and environmental pollution have become increasingly more serious. As one of the strategic new industries, electric vehicle (EV) has received widespread attention. With the large-scale growth of EVs, the charging and discharging performances not only control efficiency and lifetime of EV, but they also affect the quality of power grid [1–3]. Although the structure of uncontrolled or phase-controlled grid-side converter is simple, it is more likely to cause non-negligible harmonic pollution to electrical power system. It is based on this consideration that active power filter (APF) or power factor correction (PFC) circuit is proposed in [4]. These structures could suppress effectively the harmonic pollution. However the burden and the complexity of electric power system were increased at the same time.

With the emergence and rapid development of vehicle to grid technology (V2G), which means a bidirectional interactive relation of information and energy between EV and power grid [5], one type of on-load/off-load charger, adopted a three-phase voltage source PWM converter and bi-directional dc/dc converter, has become a hot research field. On the premise of keeping charging function, the services of perk load shifting and reactive power compensation for power grid are realized by rationally designing control strategy of the charger just mentioned. Meanwhile the charger, which is an energy feedback system, can operate efficiently in a wider range of output power. Moreover the harmonic pollution of this charger can be suppressed and then the power factor will be promoted.

* *Corresponding author.*
E-mail address: jiaoran0418@sina.com (R. Jiao).

http://dx.doi.org/10.1016/j.ijhydene.2017.04.194

Please cite this article in press as: Jiao R, et al., Dead-beat instantaneous power control for off-board charger of electric vehicle for V2G application, International Journal of Hydrogen Energy (2017), http://dx.doi.org/10.1016/j.ijhydene.2017.04.194

At present, there are many studies about the control strategy for V2G charger. The interaction of power grid and EV charger was presented in Ref. [8]. Refs. [9,10] focused on the charging mode of EV. However there was little research on the control strategy for three-phase voltage source PWM converter, in spite that it is one of key parts influencing power quality. A voltage–current double closed-loop, which is adopted feed-forward decoupling control strategy, was presented in [12,13] to significantly improve the robustness. But the complexities of these systems were increased by PI parameters. A current dead-beat control structure based on power feed-forward, which is consisted of PI outer voltage loop and inner current dead-beat control loop, was proposed in [14]. Because it needed no measurement of the grid voltage phase, this method simplified control process. But there was a constant phase static error in ac current, for the reason that this controller is a one order time-delay system, which possessed low inertia property.

Based on the above analysis, a double closed loop, consisted of outer voltage loop and inner instantaneous power loop for V2G charger, is presented in this paper. To achieve instantaneous power fast tracking, the dead-beat instantaneous power control structure is adopted. Simulation and experiment results verify the effectiveness and feasibility of the proposed control strategy.

The topology of off-board V2G charger

As a interface circuit of three-phase ac power grid and EV power battery, the topology of off-board V2G charger is shown in Fig. 1. The energy of the control system can flow bidirectional freely. On the premise that EV power battery is charged reliably, electric energy waste can be avoided if the energy is feedback to grid in discharging state. The structure mainly contains three-phase voltage source PWM grid-side converter, dc filter and bi-directional dc/dc converter.

Where, e_a, e_b and e_c are three-phase grid voltages, respectively. i_a, i_b and i_c are ac grid currents, respectively. u_{ra}, u_{rb} and u_{rc} are switching voltages of grid-side converter. u_{dc} is dc-bus voltage. L_1 and R_1 are filter inductor and equivalent resistor in the ac side, respectively. C_1 is filter capacitor of dc-bus. L_d and C_d are inductor and capacitor in the power battery side of bi-directional dc/dc converter, respectively. The variable E_v denotes EV power battery.

Control strategy for off-board V2G charger

Control strategy for grid-side converter of off-board charger

As shown in Fig. 1, making the circuit on the right of dc filter equivalent to a series structure, composed by dc-source and equivalent resistor, a topology of three-phase voltage source PWM grid-side converter of off-board charger is achieved. The control goals of this controller are expressed as follows: (1) Grid-side current should be sinusoidal. (2) Phase synchronization between grid-side current and grid voltage is realized. (3) bi-directional dc/dc converter can output constant dc voltage in discharge state. In order to facilitate modeling for three-phase voltage source PWM grid-side converter, the following assumptions are set up: (1) grid voltage is ideal three-phase symmetrical sinusoidal wave; (2) All IGBT switch devices in converter are ideal. Dead-time effect and energy loss of all switches can be ignored; (3) Saturation effect of ac-side filter inductor can be ignored.

Based on the KVL law, the voltage equations for three-phase voltage source PWM grid-side converter in $\alpha\beta$ two-phase static coordinate are expressed as follows.

$$\begin{cases} L_1\dfrac{di_\alpha}{dt} = -R_1 i_\alpha - u_{r\alpha} + e_\alpha \\ L_1\dfrac{di_\beta}{dt} = -R_1 i_\beta - u_{r\beta} + e_\beta \end{cases} \tag{1}$$

where, e_α and e_β are α axis and β axis components of grid voltage, respectively. i_α and i_β are α axis and β axis components of grid-side current, respectively. $u_{r\alpha}$ and $u_{r\beta}$ are α axis and β axis components of switching voltage of grid-side converter, respectively.

According to the instantaneous reactive power theory, the mathematic models of instantaneous active and reactive power of three-phase voltage source PWM grid-side converter are calculated as follows.

$$\begin{cases} p = e_\alpha i_\alpha + e_\beta i_\beta \\ q = e_\beta i_\alpha - e_\alpha i_\beta \end{cases} \tag{2}$$

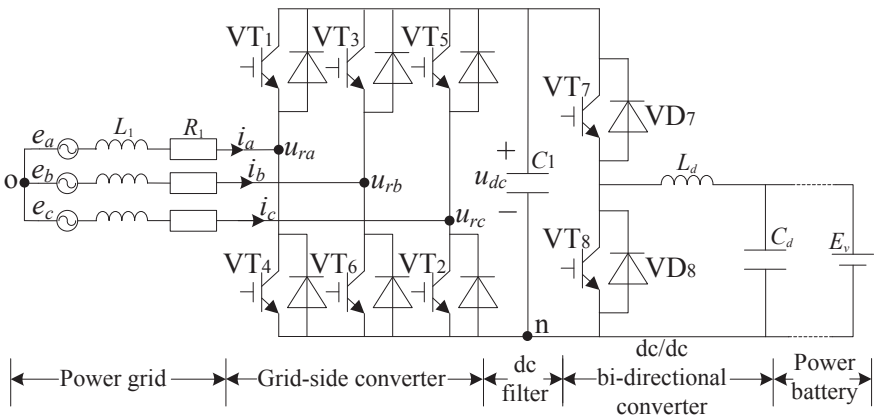


Fig. 1 – The topology of non-vehicular charger of electric vehicle for V2G.

Please cite this article in press as: Jiao R, et al., Dead-beat instantaneous power control for off-board charger of electric vehicle for V2G application, International Journal of Hydrogen Energy (2017), http://dx.doi.org/10.1016/j.ijhydene.2017.04.194