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# Lightweight Controllable Charging Load for Motion Detection of Off-Board Charger

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**Abstract.** In view of the fact that the electronic load used in the on-site detection of the electric vehicle off-board charger is large and heavy, and it would be limited by some external factors such as the space and load of the detection vehicle and the height of the underground garage. In addition, considering that if using the power batteries of mobile detection vehicle as charging load directly, its charging modes and parameters are unitary, the state of charge (SOC) and electromotive force also cannot be flexibly set, which would result in long charging time, low efficiency, limited test range and items. This paper proposes a topological scheme that the lightweight controllable charging load consists of a vehicle-mounted power battery pack and a cascaded DC/DC converter, researches the double-closed loop control methods such as constant input voltage, constant load resistance as well, further comes true the typical working modes: constant input voltage, constant load resistance. Moreover the operating modes have the ability to continuously adjust in the rated range. In a word, the proposed scheme can achieve self-test of the off-board charger while reducing the weight of the charging load. Finally, the simulation model in Matlab/Simulink is established to verify the feasibility of the proposed topology and the effectiveness of the control methods.

## 1. Introduction

In today's energy-saving and environmentally-friendly environment, new-energy vehicles such as electric vehicles have become the main direction of contemporary automobile development. During the 12th Five-Year Plan and the 13th Five-Year Plan, the Chinese government has successively issued a series of policies to promote the development of new energy vehicles such as electric vehicles [1], and the research on the existing problems of electric vehicles is also deepening. With the large-scale development of electric vehicles in China, the importance of the operation and maintenance of charging infrastructure has gradually emerged, therefore, the mobile detection equipment of off-board



charger has gradually been recognized and concerned by the industry: the literature [2] developed a test system of electric vehicle charging equipment based on virtual battery technology. The test system can perform functional test, electrical performance test, interface and communication test, power quality characteristic test and additional functional test; In literature [3], a non-vehicle charger embedded control system capable of controlling, monitoring the charging process and displaying charging data in real time was designed and implemented, and the system hardware and software platform were built. In order to meet the needs of standardization of on-site inspection of off-board charger, relevant national standards and enterprise standards have also been promulgated [4].

At present, the on-site detection of off-board chargers mostly uses traditional DC electronic loads, and its working principle is to directly consume power through the internal power FET (IGBT) or power transistor (GTR) dissipated power, a large radiator is needed to dissipate the heat, which causes the DC electronic load to be bulky and heavy. When DC electronic loads are used for on-board testing of off-board chargers, it is limited by the external factors such as the space of the loaded vehicle, the load or the height of the underground garage, which restricts the practical application of class mode in field testing of off-board chargers. If the electric vehicle is selected as the mobile platform and the power battery pack of the vehicle is directly used as the charging load during the field test, the additional configuration charging load can be omitted, and the charged electric energy is stored in the vehicle battery, and is not wasted. Compare with the above-mentioned DC electronic load, this mode has advanced concepts and high economical efficiency. At the same time, from the formal point of view, the built-in test environment is a real test environment, which can directly test the actual running performance and state.

However, in practical applications, if a battery pack consists of a single power battery pack and a battery management system, its charging mode, charging parameter and a battery condition are determined by the battery management system and the state of charge (SOC). For a fixed capacity battery pack, its operating mode and charging parameters will be unchangeable. In addition, the SOC and voltage of the power battery pack are determined by the actual energy storage of the battery. The SOC and voltage [5] cannot be adjusted autonomously during the test. Therefore, the entire test process is passive, meantime the testing process takes a long time, the efficiency is low, the test range and test items are limited, and the independent testing of the off-board charger cannot be realized.

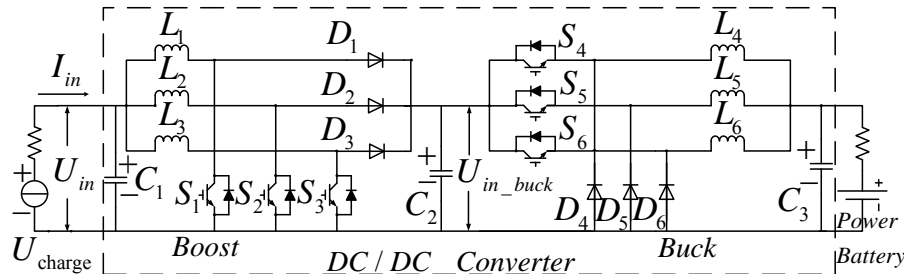
Based on the above problems, this paper proposes a lightweight and controllable charging load scheme for on-site detection of off-board chargers, which achieves the design goal of high charging power density, small size and light weight, and is suitable for mobile loading transportation. Specifically, the electric vehicle is used as the mobile detection car, when the on-site test is carried out in the parking state, the charging load is composed by a vehicle-mounted power battery pack with a cascaded DC/DC converter. The design of control strategy of the DC/DC converter makes the charging load to have a variety of operating modes such as constant input voltage, constant load resistance, and the ability to continuously adjust within the rated range, while achieving the self-test of the off-board charger while meeting the lightweight of the charging load.

## 2. Main circuit topology and working principle

### 2.1. Main circuit topology

The main topology of the lightweight controllable charging load designed in this paper is shown in Figure 1. The lightweight controllable charging load is composed of a vehicle-mounted power battery pack with a cascaded DC/DC converter. The DC/DC converter consists of a front-stage boost converter and a post-stage buck converter and adopts a three-phase interleaved parallel structure, which can effectively reduce the current stress of the switch tube and the output current ripple of the converter, and improve the converter capacity and power quality. The boost converter consists of an input side capacitor  $C_1$ , three inductors ( $L_1 \sim L_3$ ), three IGBT ( $S_1 \sim S_3$ ) and three freewheeling diodes ( $D_1 \sim D_3$ ). The buck converter consists of an output side capacitor  $C_3$ , three inductors ( $L_4 \sim L_6$ ),

three IGBT ( $S_4 \sim S_6$ ) and three freewheeling diodes ( $D_4 \sim D_6$ ).  $C_2$  is the cascade-side capacitor which provides voltage support for the cascade-side.

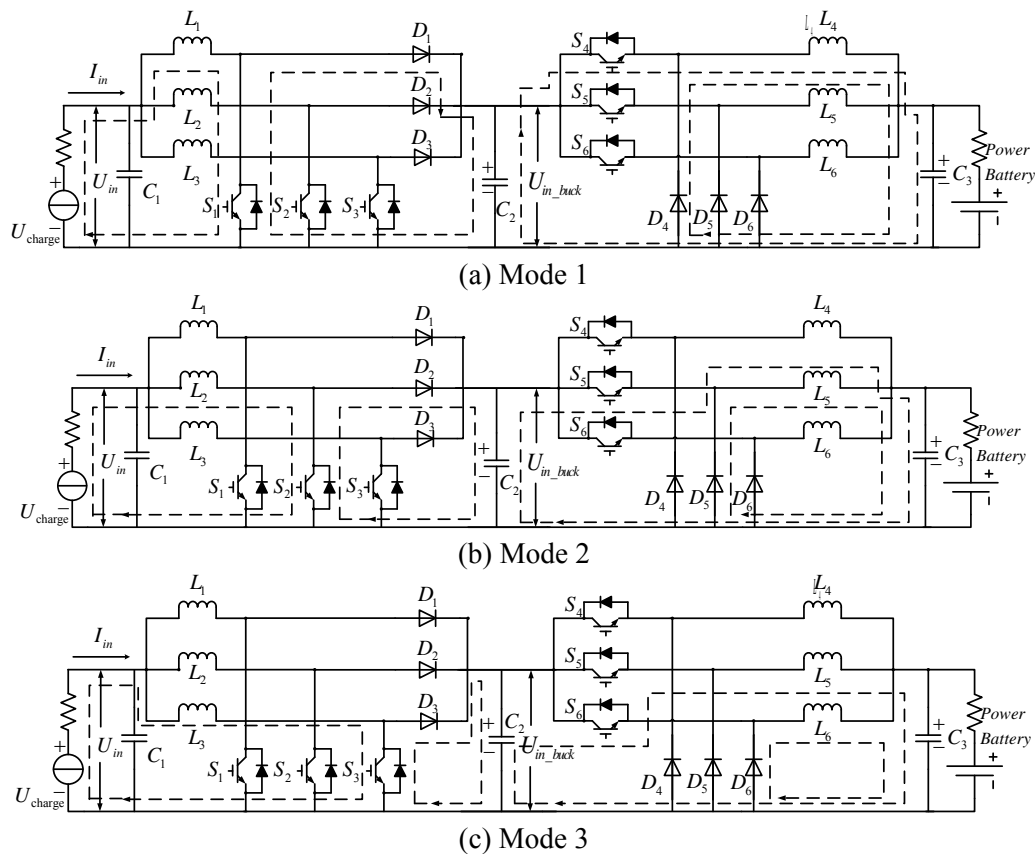


**Figure 1.** Main topology of Lightweight controllible charging load

## 2.2. Working principle

During normal operation, the off-board charger charges the charging load. In one switching cycle  $T_s [t_0 \sim t_6]$ , the three-phase switching tubes of the converter alternately turn on in sequence. The duty cycles of the IGBTs  $S_1, S_2, S_3$  are  $d_1, d_2, d_3$  respectively and  $d_1 = d_2 = d_3$ . The duty cycles of the IGBTs  $S_4, S_5, S_6$  are  $d_4, d_5, d_6$  respectively and  $d_4 = d_5 = d_6$ . The purpose of this design is to ensure the current sharing of the phases of the three-phase interleaved DC converter to avoid the occurrence of circulating current.

In one switching cycle  $T_s$ , the converter have three operating modes, corresponding to mode 1, mode 2, mode 3 respectively, as shown in Figure 2:



**Figure 2.** Operating mode of Boost circuit

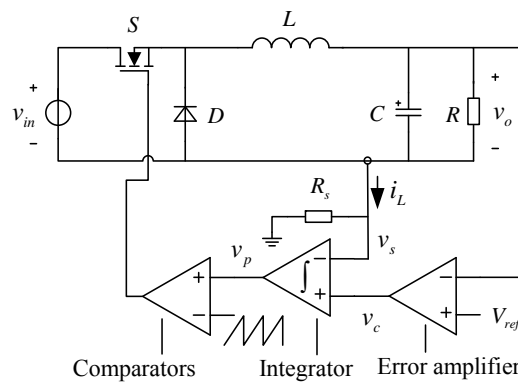
Mode 1  $[t_0 \sim t_2]$ , as shown in Figure 2(a): Boost converter first phase operation, at  $t_0$  time,  $S_1$  turn on, inductor  $L_1$  is charging, inductor current  $i_{L1}$  continues to increase. At  $t_1$  time,  $S_1$  turn off, the circuit continues to flow through the diode  $D_1$ , the inductor current  $i_{L1}$  decreases; Buck converter first phase operation, at  $t_0$  time,  $S_4$  turn on, inductor  $L_4$  is charging, inductor current  $i_{L4}$  continues to increase. At  $t_1$  time,  $S_4$  turn off, the circuit continues to flow through the diode  $D_4$ , the inductor current  $i_{L4}$  decreases.

Mode 2  $[t_2 \sim t_4]$ , as shown in Figure 2(b): Boost converter second phase operation, at  $t_2$  time,  $S_2$  turn on, inductor  $L_2$  is charging, inductor current  $i_{L2}$  continues to increase. At  $t_3$  time,  $S_2$  turn off, the circuit continues to flow through the diode  $D_2$ , the inductor current  $i_{L2}$  decreases; Buck converter second phase operation, at  $t_2$  time,  $S_5$  turn on, inductor  $L_5$  is charging, inductor current  $i_{L5}$  continues to increase. At  $t_3$  time,  $S_5$  turn off, the circuit continues to flow through the diode  $D_5$ , the inductor current  $i_{L5}$  decreases.

Mode 3  $[t_4 \sim t_6]$ , as shown in Figure 2(c): Boost converter third phase operation, at  $t_4$  time,  $S_3$  turn on, inductor  $L_3$  is charging, inductor current  $i_{L3}$  continues to increase. At  $t_5$  time,  $S_3$  turn off, the circuit continues to flow through the diode  $D_3$ , the inductor current  $i_{L3}$  decreases; Buck converter third phase operation, at  $t_4$  time,  $S_6$  turn on, inductor  $L_6$  is charging, inductor current  $i_{L6}$  continues to increase. At  $t_5$  time,  $S_6$  turn off, the circuit continues to flow through the diode  $D_6$ , the inductor current  $i_{L6}$  decreases.

### 3. Control method

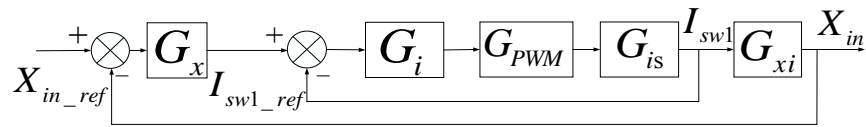
The lightweight controllable charging load designed in this paper uses average current control, and its control schematic is shown in Figure 3. The integrator in the figure is the current integrator of the current inner loop,  $V_p$  is the output of the integrator, and the sawtooth wave is the carrier signal. It can be seen from Figure 3 that the average current control is to add a current integrator to the current loop to control the average value of the inductor current. The working principle is as follows: first, the sampled inductor current signal  $V_s$  is compared with the output of the voltage outer loop error amplifier  $V_c$ , it is processed by the current integrator, and then compared with the sawtooth wave, and finally the switch tube control signal with a certain pulse width is obtained to control the converter [6].



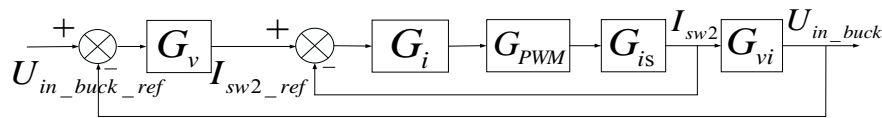
**Figure 3.** Schematic of Average current control

The main topology of the charging load designed in this paper adopts three-phase interleaved parallel structure. The control strategy of the three-phase switching tube is basically the same. Except

the initial phase angle of the three-phase high-frequency triangular carrier is  $120^\circ$  out of, and the control block diagram of the charging load is as the Figure 4 shows. The front-stage Boost converter adopts double closed-loop control. The outer ring corresponds to different working modes: voltage, current, regulator, and the inner ring is switch-tube current regulator. The post-stage Buck converter adopts double closed loop control too, the outer ring is a voltage regulator, and the inner ring is a switch tube current regulator.



(a) Control block diagram of boost converter



(b) Control block diagram of buck converter

**Figure 4.** Control diagram of charging load

$X$  in the Figure 4 (a) represents the controlled object, corresponding to the input voltage  $U_{in}$ , load resistance  $R_l$ ,  $G_x$  and  $G_i$  are the transfer function of the outer loop regulator and the inner loop regulator respectively,  $G_{is}$  and  $G_{xi}$  are respectively the transfer function of control signal to the switch-tube current and the transfer function of the controlled object to the switch-tube current. In the Figure 4(b),  $G_v$  and  $G_i$  are the transfer function of the outer loop regulator and the inner loop regulator respectively,  $G_{is}$  and  $G_{vi}$  are respectively the transfer function of control signal to the switch-tube current and the transfer function of the input voltage to the switch-tube current [6].

#### 4. Modeling and simulation

In order to verify the feasibility of the topology and the effectiveness of the control method, the simulation model of the lightweight controllable charging load working in two modes was built by Matlab/Simulink simulation software. Each module in the simulation uses the modules in SimPowerSystems.

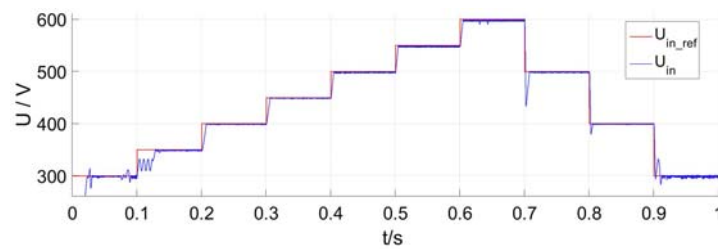
##### 4.1. Mode of Constant input voltage

The parameters of the simulation model in constant input voltage mode are shown in Table 1:

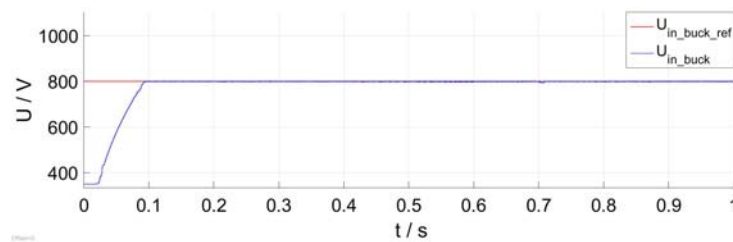
**Table 1.** Model parameters of constant voltage mode

parameters	numerical value
Input current/A	30
Output voltage/V	350
cascading-side voltage /V	800
reference value of input voltage /V	300~600
inductance/mH	0.5
input-side capacitance / $\mu$ F	2200
cascading-side capacitance / $\mu$ F	2200
output-side capacitance / $\mu$ F	2200
switch frequency of IGBT/kHz	20

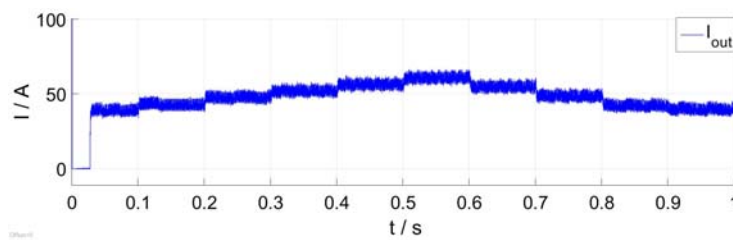
The simulation results are shown in Figures 5-7:



**Figure 5.** Waveform of input voltage



**Figure 6.** Waveform of Cascading-side voltage



**Figure 7.** Waveform of output current

According to Figure 5, when the reference value of input voltage changes, the waveform can be stabilized within 0.05s, the response speed meets the requirements, and the steady-state error is within 0.5%, which meets the requirements. According to Fig. 6, the voltage on the cascading-side achieves stable within 0.1 s, the response speed meets the requirements, and the steady state error is within 0.5%, which meets the requirements.

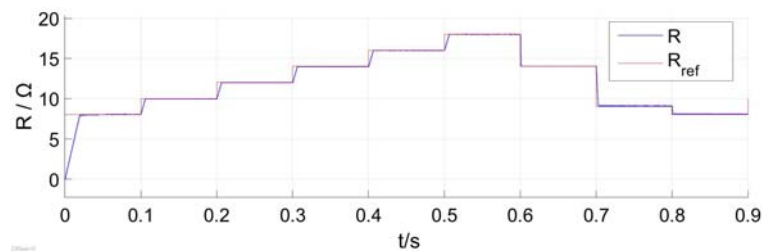
#### 4.2. Mode of Constant load resistance

The parameters of the simulation model in constant load resistance mode are shown in Table 2:

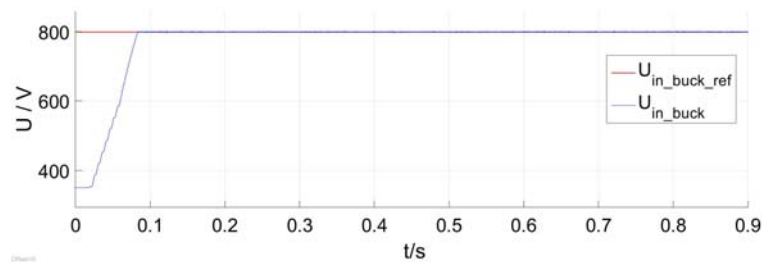
**Table 2.** Model parameters of constant load resistance mode

parameters	numerical value
Input current /A	30
Output voltage/V	350
cascading-side voltage /V	800
reference value of load resistance /V	8~18
inductance/mH	0.5
input-side capacitance / $\mu$ F	2200
cascading-side capacitance / $\mu$ F	2200
output-side capacitance / $\mu$ F	2200
switch frequency of IGBT/kHz	20

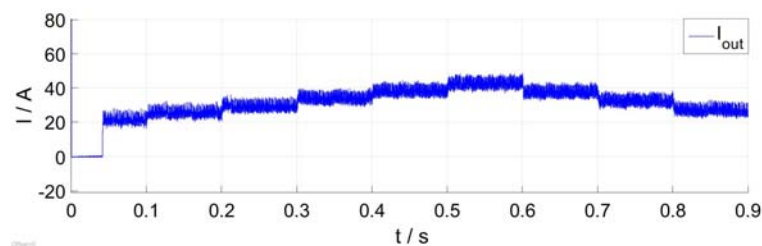
The simulation results are shown in Figures 8-10:



**Figure 8.** Waveform of load resistance



**Figure 9.** Waveform of Cascading-side voltage



**Figure 10.** Waveform of output current

According to Figure 8, when the reference value of load resistance changes, the waveform can be stabilized within 0.05s, the response speed meets the requirements, and the steady-state error is within 0.5%, which meets the requirements. According to Fig. 9, the voltage on the cascading-side achieves stable within 0.1 s, the response speed meets the requirements, and the steady state error is within 0.5%, which meets the requirements.

## 5. Conclusion

In view of the fact that the electronic load used in the on-site detection of the electric vehicle's off-board charger is large and heavy, and it would be limit by some external factors such as the space and load of the detection vehicle and the height of the underground garage. In addition, considering that if use the power batteries of mobile detection vehicle as charging load directly, its charging modes and parameters are unitary, the state of charger (SOC) and Electromotive Force also cannot be flexibly set. These problems could result in long charging time, low efficiency, limited test range and items. This paper proposes a topological scheme that the lightweight controllable charging load consists of a vehicle-mounted power battery pack and a cascaded DC/DC converter, researches the double closed loop control methods such as constant input voltage, constant load resistance, constant input power and constant resistance of load, then comes true the typical working modes: constant input voltage, constant load resistance. Besides the operating modes has the ability to continuously adjust in the rated range.



The practical effects that the program can achieve are as followings: First, the lightweight controllable charging load has high power density, small size, light weight, and is suitable for on-site detection of off-board chargers for transportation requirements of mobile loading and site limits. Second, the basic parameters and charging mode of the lightweight controllable charging load can be adjusted independently according to the requirements of the field tests, so the self-test of the off-board charger is realized. Thirdly, selecting the electric vehicle as the mobile platform, and using the power battery packs as the charging load directly in the field test can save the extra configuration of charging load and store the electric energy in the test into the vehicle battery directly instead of dissipating in the form of heat, which make the whole system more effective and economic. Finally, the feasibility and effectiveness of the proposed scheme are verified by building a simulation model in Matlab/Simulink environment.

### Acknowledgments

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