Design of Vehicle Charger for Pure Electric Vehicle Based on MATLAB Simulation

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Abstract—In this paper, the basic principle of the on-board charger of electric vehicle is studied and analyzed, and the design scheme of vehicle charger with two-stage transformation structure is proposed. The former converter adopts boost active power factor correction circuit to improve power factor and reduce total harmonic distortion; the latter adopts phase shifted full bridge ZVS inverter circuit to realize electrical isolation and DC/DC conversion. According to this scheme, a 2kW vehicle charger is designed. The charging mode adopts three-stage charging method to charge lithium battery pack, and the three-stage charging is simulated. The results are consistent with the requirements of three-stage charging curve.

1. Introduction
With the continuous development of economy, the demand for motor vehicles is also rising rapidly, and the demand for energy is increasing. However, the non-renewable resources such as oil and natural gas are increasingly in short supply. The problems of environmental pollution and ecological damage are serious. As a new energy vehicle, electric vehicle has the advantages of high energy utilization, zero pollution and reducing valley power waste[1].

Charger is a kind of power electronic equipment. It is the core equipment for electric vehicle to convert AC power into electric energy demand form of electric vehicle battery, and it is the key source of electric vehicle energy. According to the location of the charger, it can be divided into on-board charger and off-board charger. The offboard charger is usually installed in the fixed place such as charging station, which can charge most power batteries. However, the offboard charger limits the range of activities of electric vehicles and limits its convenience. The charging motor is installed on the electric vehicle, and the special power battery can enhance the pertinence and efficiency. It can be charged in the place with AC mains socket, and the charging convenience is greatly improved. Therefore, the car charger market is widely used.

In this paper, a kind of vehicle charger is designed, the topology structure of the system is given, the working principle and control mode are expounded, and the test is carried out.

2. STRUCTURE OF ELECTRIC VEHICLE CHARGER SYSTEM
As a bridge of power conversion between 220 V AC mains power and lithium battery pack, the function of vehicle charger is to convert 220 V AC to DC through full bridge uncontrolled rectifier and filter circuit. Then, the required DC power is supplied to lithium battery pack by isolated DC-DC converter circuit. In the DC-DC conversion circuit work project, the battery management system transmits the lithium battery terminal voltage, battery current and single battery voltage as control input
signals, and sends control signals to the DC-DC conversion circuit according to the controller to make the DC-DC conversion circuit work.

\[\text{Rectifying and filtering circuit} \rightarrow \text{DC-DC Converter} \rightarrow \text{Vehicle power battery pack} \rightarrow \text{Battery voltage, current and temperature detection circuit} \rightarrow \text{Battery management system} \rightarrow \text{AC power supply} \]

**Figure 1. Structure diagram of vehicle charger**

At the same time, the power factor correction circuit (PFC) is added to the rectifier circuit, which can improve the power factor of the input voltage and suppress the high-order harmonics. It has little pollution to the power grid and meets the requirements of low harmonic and high power factor of equipment. This structure of the car charger is generally large in size and high in cost, and can be used in high-power, large capacity charging system.

### 3. HARDWARE SYSTEM DESIGN OF VEHICLE CHARGER

The main power circuit of electric vehicle charger is mainly composed of boost APFC circuit and phase shifted full bridge ZVS circuit. The single-phase alternating current flows into the single-phase full bridge uncontrollable rectifier circuit after bidirectional flow EMI filtering. Under the function of boost type correction circuit, the alternating current is rectified into direct current, which is input to the later stage circuit. The phase-shifting full bridge ZVS circuit in the later stage converts the DC voltage into high-precision DC that can be accepted by lithium battery pack.

#### 3.1 Design of AC-DC rectification circuit

AC-DC rectification circuit mainly includes the following two parts, as shown in Figure 2:

- The full bridge uncontrollable rectifier circuit is mainly used to convert AC mains power into sinusoidal half wave pulsating DC current, which is mainly composed of rectifier diodes.
- Boost active power factor correction (APFC) circuit. The DC-DC active power converter is added between the uncontrollable rectifier circuit and the filter circuit. Through the PWM control circuit, the current waveform of the AC side input terminal can be in phase with the input voltage waveform[2]. And the circuit to achieve DC voltage stabilized output, improve the power factor, make it approximately 1. The topology of single-phase boost APFC correction circuit is shown in Figure 2.

**Figure 2. AC-DC rectification circuit**

#### 3.2 Design of isolated DC-DC converter circuit

DC-DC converters can be divided into two types: non isolated and isolated. Compared with the non isolated DC-DC converter, the isolated DC-DC converter can realize the electrical isolation between the power supply part and the output part, and improve the system security. At the same time, a high frequency transformer is set in the isolated converter circuit, which can change the ratio of primary and secondary turns of the transformer and change the output voltage. The characteristics of several common isolated DC-DC converter circuits are shown in Table 1.
It can be seen from table 1 that the output power of the full bridge DC-DC converter circuit is the maximum when the power transistor with the same voltage withstand value is selected. At the same time, it is easier to realize ZVS to reduce the power loss of the system. It is suitable for vehicle charger in high power situation. The main circuit of isolated DC-DC converter circuit is shown in Figure 3.

### TABLE 1. COMPARISON OF DC-DC CONVERTER CIRCUIT CHARACTERISTICS

| Topological structure classification | Table Column Head | Table Column Head | Table Column Head | Degree of ZVS implementation |
|-------------------------------------|-------------------|-------------------|-------------------|-----------------------------|
|                                     | output power      | Input voltage / V | Switch withstand voltage / input voltage |                              |
| Flyback small                       | 5-500             | 2                 | difficultly       |                              |
| Forward type                        | 5-500             | 1.7               | difficultly       |                              |
| push-pull                           | 50-1000           | 2                 | difficultly       |                              |
| half-bridge                         | 50-1000           | 1                 | difficultly       |                              |
| Full bridge                         | 50-1000           | 1                 | easily            |                              |

The full bridge inverter circuit is composed of power FET T1 ~ T4. T1 and T4 are one arm, T2 and T3 are the other. Each axle arm is the same driving signal, and the two groups of driving signals are in inverse phase. When T1 and T4 are on, T2 and T3 are turned off. vice versa. In the switching process of two groups of switching devices, a certain dead zone should be reserved between the driving signals, so the duty cycle of driving signals should be less than or close to $1/2$. D1 ~ D4 are parasitic diodes. The resonant inductor LR, the resonant capacitor Cr and the excitation inductor LM constitute a series resonant circuit with the equivalent load on the secondary side. Diode D5 and D6 constitute a full bridge rectifier circuit, and the filter capacitor CF of the later stage realizes voltage filtering.

![Figure 3. Main circuit of isolated DC-DC](image)

3.3 **Auxiliary circuit design**

The can communication circuit of vehicle charging system is mainly the communication between vehicle charger and battery management system (BMS). It can implement the charging operation logic, monitor the characteristics of BMS battery in real time, select the optimal battery charging curve, so as to achieve efficient and rapid charging of the battery. The auxiliary power supply circuit can provide energy supply for some low-voltage circuits such as control chip, communication module and so on. It can provide 24, 12, 5, 3.3V voltage values. It is required that the on-board charger only works when it is in charging state. Therefore, the low-voltage power supply for the vehicle charger is converted from 220 V AC mains power, not from the 12 V low-voltage battery of the car. The CAN bus and the charging rate can avoid negative effects on the static load process.

3.4 **Auxiliary circuit design**

The control and protection circuit mainly includes signal acquisition, logic operation and drive output. According to the set logic operation, the current and voltage signals of the relevant positions of the acquisition circuit are output to the corresponding switch tube and relay driving signal, so as to realize
the efficient and intelligent charging and protection control of the power battery. Because this part of the circuit is relatively simple, this paper will not repeat this.

4. Charging mode of vehicle charger

4.1 Charging mode of vehicle charger

At present, the mainstream charging mode of charger generally adopts three-stage charging mode, which is roughly divided into three stages: constant current charging stage, constant voltage charging stage and floating charging stage[3]. In this paper, T2 interrupt service program is used to complete the three-stage charging subroutine. During the whole charging process, the vehicle charger and the battery management system (BMS) communicate continuously. After the handshake phase and configuration phase, they enter the charging stage. In the charging stage, the battery management system controls the charger to charge the battery pack along the charging curve. The battery management system sends the measured charging voltage V, charging current I, maximum and minimum temperature of the battery pack to the charger. The vehicle charger monitors the whole charging process according to the state of battery charging. The flow chart of three-stage charging subroutine of charger is shown in Figure 4.

![Flow chart of three section charging subroutine of charger](image)

4.2 PID control

The output adjustable control strategy used in this paper is digital PID control. This is a mature and widely used control method. The system structure diagram is shown in Figure 5.

The proportion link shown in the figure can reduce the steady-state error of the system and improve the control accuracy of the system; The integral link can realize the system adjustment without static error; Differential links can achieve advanced adjustment.
The proportional, integral and differential parts of the deviation e(t) are combined to form a control variable, and then the controlled object is controlled. The controlled object is the output current and voltage of charger system. In the process of charging lithium batteries, battery management system (BMS) continuously collects the voltage and current y(t) of lithium batteries. According to the collected current and voltage signals, which charging stage the lithium battery pack should be in, and then the corresponding voltage or current given value r(t), together with the current and voltage sampling values, are transmitted to the main control CPU of the charger through can communication. The CPU adjusts these signals by PID to get a control value u(t), which can control the size of phase shift angle α, so that the output voltage can be controlled to make it the same as the given value.

PID (proportional integral differential) control algorithm can dynamically adjust the phase control angle according to the output voltage and the feedback of output filter inductance current, so that the output value is the same as the expected value. PID algorithm needs to select three suitable parameters. In this design, incremental PID algorithm is used. The PID flow chart is shown in Figure 6.

**4.3 Generation of pulse width modulation (PWM) signal**

The DSP controller is TMS320F2812. Event manager EVA and EVB generate PWM control signal of power switch. The comparison unit 1 of EVA generates pwm1 and pwm3, and controls the two IGBTs on the leading leg of the full bridge converter: VT1 and vt4[4]. The comparison unit 4 of EVB generates pwm2 and pwm3 to control the two IGBTs on the lagging leg of the full bridge converter: vt2 and vt4. In order to avoid simultaneous conduction of power switches on the same bridge arm, it is necessary to ensure a certain dead time between two PWM control signals. In the whole process, the parameters of the bridge leading controller and the EVA controller can be changed.
5. Simulation test
The main control circuit of vehicle charger system is simulated by Simulink. In order to ensure the good charging of lithium battery, the three-stage charging method is adopted. In this experiment, 80 lithium batteries with capacity of 10Ah are connected in series. The constant current charging current is 10A. At the same time, the voltage value is stable at constant voltage stage, and the charging voltage of lithium battery pack is 398v. The third stage is floating charging, in which the floating charging voltage is 388.5v. Before charging the lithium battery pack, the can communication between the vehicle charger system controller and BMS is established. The collected battery voltage, current and other parameters are transmitted to the charger system control circuit through BMS. If the battery pack is over discharged and the voltage of single lithium battery is less than 2.9v, it is necessary to pre charge the battery pack with small current first, and the charging current is 1A; if the voltage of single battery is 2.9v < U < 4.2V, the vehicle charger enters the constant current charging stage with large current; if the voltage U of single battery U > 4.2V, the charger directly enters the constant voltage charging stage. If the charging current of lithium battery pack is less than 1A, it will enter floating charging stage.

![Three stage charging curve](image)

The charging curve of three-stage charging mode is shown in the figure. In the constant current charging stage, the current value is 200A. 0.47s is converted to constant voltage charging, and the voltage value is 400V. In 0.9s, the floating charge voltage is 388v. The floating charging voltage and constant voltage charging voltage are determined by the battery management system, and then PID control is carried out through the charger control system to control the beginning of the switch tube. In this way, the output voltage is controlled to make the output voltage stable.

The curves of voltage at both ends of MOSFET and current flowing through MOSFET are shown in Figure 8. The voltage curve and current curve do not overlap each other. Four switches realize ZVS. The simulation results show that ZVS improves the conversion efficiency of the whole system by 1.3 times.

![Voltage current curve of IGBT](image)

6. Conclusion
In this paper, a design scheme of vehicle charger is proposed. According to this scheme, a 2kW prototype is made. The three-stage charging method is used to charge the lithium battery pack, and the three-stage charging is simulated. The results are consistent with the requirements of the three-stage charging curve. The PID parameters of the current loop and voltage loop of the control circuit are designed and verified by simulation. The simulation results show that the current and voltage output of
the main circuit can be realized and adjusted according to the requirements of the voltage loop and current loop. The software and hardware design of the main control circuit is completed, the PWM subroutine is compiled, and the function of the main circuit is preliminarily tested. This design uses three-stage charging, although it can meet the charging requirements of lithium battery pack in theory, the charging speed is not enough. The realization method of fast charging needs further research.

Acknowledgment
This work was supported in part by General program of National Natural Science Foundation of China (61873334) and in part by the natural science project (17YCZDZR08).

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