

## DC Power System of Electric Vehicle

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### Abstract

In recent years, environmental and energy problem has become one of the world's hot spot problems. Today, the road cars not only consume a lot of oil resource, but also cause serious pollution to human survival environment. Therefore, to save energy and protect environment, a green environmental friendly electric car instead of fuel car will be needed for sustainable development of the society. Electric vehicle has no pollution, low noise, high efficiency, diversification, simple structure and convenient maintaining; the development of green cleaning electric vehicle is the trend, and the inevitable choice. The power supply system of electric vehicle can be divided into three parts, the battery charging system, motor drive system and dc load power supply system. This paper mainly studies the dc load power supply system. Main function is to convert the high-voltage of the battery in the electric vehicle into low voltage output, provide the power supply for the low voltage dc load, including the car safety system, windshield wiper system, audio system. On the basis of the analysis of the parameters, this article designs the converter, sets up the principle prototype, analyzes the experimental results and finally makes conclusion. The vehicle power supply is green, environment friendly, high-efficiency, digital and intelligent.

**Keywords:** electric vehicle, phase shift control, TMS320F28035, flyback

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### 1. Introduction

The whole power supply system of electric vehicle can be divided into three parts, 1) the battery charging system, it translates alternating current (AC) in the charging pile into direct current (DC), and charges the electric vehicle battery. 2) Motor drive system, which translates the battery output dc bus voltage into alternating current (AC), and drives the AC motor. 3) Dc load power supply system, the main function is to translate the output high voltage of electric vehicle battery into low voltage output for the DC load, such as car security system, windshield wiper system, and audio system.

The whole power supply system diagram is shown in Figure 1.

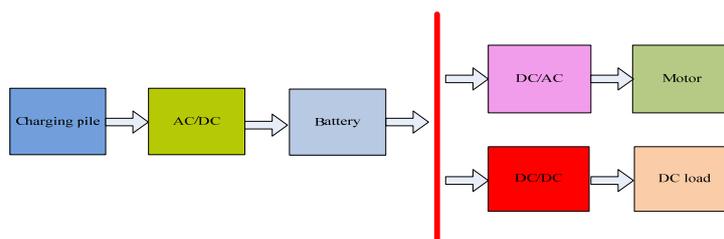


Figure 1. Power System Block Diagram of Electric Vehicles

This paper is based on the DC/DC power supply system, namely the battery and DC load. The main technical index of the converter is shown in Table 1.

Considering the high input voltage, low output voltage, and high power characteristics, this paper selects full bridge converter as its main circuit topology. In order to improve the overall performance of the converter, the full bridge in primary side uses phase shift control mode, and the secondary uses synchronous rectifier mode. The control part is based on the DSP28035 digital controller. Auxiliary power adopts flyback converter based on UCC28600 quasi-resonant control mode. The overall block diagram of the converter is shown in Figure 2.

Parameters	Value
DC input voltage $V_{in}$	300V-380V
DC output voltage $V_o$	13.5V
Output current $I_o$	100A
Output power $P_{out}$	1.35kW
Switching frequency $f_s$	60kHz
Efficiency	96%

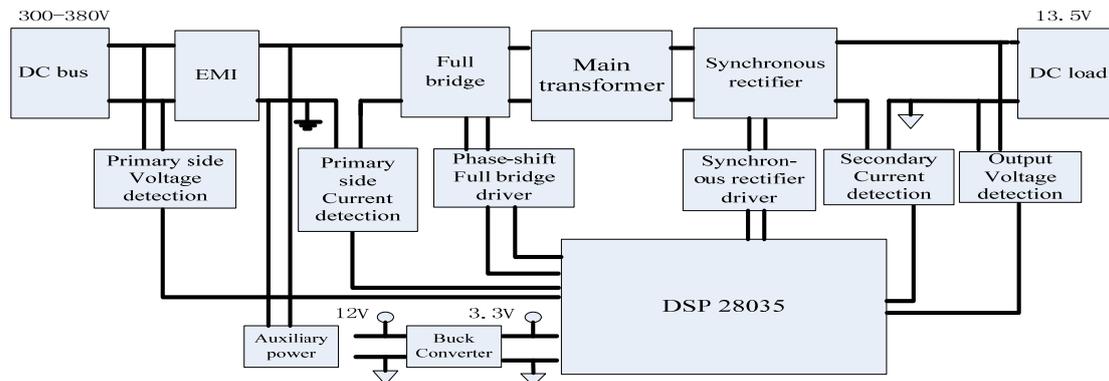


Figure 2. Block Diagram of Converter on Vehicles

## 2. Phase Shift Control Full-Bridge Converter

The full-bridge converter consists of full-bridge inverter, transformer, and rectifier filter. Full bridge converter has been widely used in high input voltage and high power applications because of its low voltage, current stress of the four switches. There are three control modes of the full-bridge inverter circuit, bipolar control, limited bipolar control and phase shift control. The secondary rectifier circuit generally has a half-wave rectification, full wave rectification, full-bridge rectification. The phase shift control has the following advantages, easy to realize soft switching of the switching devices and achieve high-frequency, miniaturization, has low switching loss, better applications of the devices' voltage and current rating, and small electromagnetic interference. Therefore, this mode is more and more widely used in high-power DC/DC converter [1-2]. Figure 3 shows the main circuit topology of the phase-shifted full-bridge.

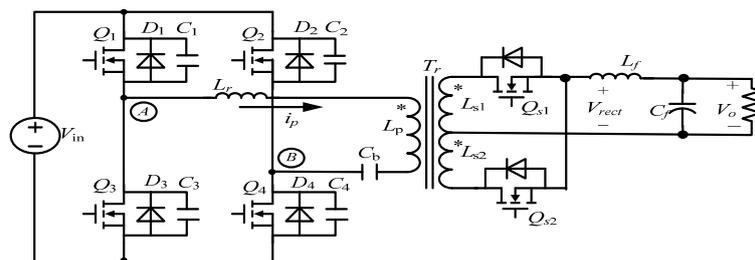


Figure 3. Block Main Schematic Circuit of Phase Shift Full Bridge

In Figure 3,  $Q_1 \sim Q_4$  are the four main switches,  $Q_1$  and  $Q_4$  are the leading bridge arm,  $Q_2$  and  $Q_3$  are the lag bridge arm.  $D_1 \sim D_4$  are the internal parasitic diode of  $Q_1 \sim Q_4$ ,  $C_1 \sim C_4$  are the parasitic capacitance of  $Q_1 \sim Q_4$ .  $L_r$  is the resonant inductor which includes the leakage inductance of the transformer and assists to achieve soft switching.  $C_b$  is the blocking capacitor in the transformer primary side in order to prevent producing DC component of the transformer primary due to the inconsistency of the switching characteristics [3].

Primary side uses positive and negative pulses as drive signals, which the positive level is on, and the negative level is off, negative drive level can accelerate the turn-off process so that ensure reliable shutdown of the switches. Secondary side adopts synchronous rectification technology, which using small on-resistance dedicated power MOSFET  $Q_{S1}$  and  $Q_{S2}$  to replace the ordinary rectifier diode thereby reducing rectifier losses. The drive signals of rectifier MOSFETS are or logical of the primary side diagonal signals, namely the drive signal of  $Q_{S1}$  is the or logical of  $Q_1$  and  $Q_4$ , only when  $Q_1$  and  $Q_4$  are turned off simultaneously, it is off, or it is on, so as  $Q_{S2}$ .

### 3. Digital Circuit Design

The control of the DC power system adopts advanced digital control, the control chip is TMS320F28035, which has a unique PWM waveform generation technique that is suitable for switching power supply, phase-shift technology, the dead zone technology, and can achieve flexible, efficient, intelligent function. The digital signal processor (DSP) has high-speed processing, small size, compact structure, high speed, and high reliability and so on. Its computing and processing capacity is enhanced 10 or 50 times compared with ordinary single-chip to ensure that the system has better control performance, so it is suitable for real-time signal acquisition, processing and control, and can improve the performance when is applied to the switching power supply [4].

The digital control chip includes input and output under-voltage, over-voltage protection, input and output over-current protection, short circuit protection, and over temperature protection. This chip takes real-time signals of the input and output voltage or current, does A/D conversion, then makes logical judgment, and executes protection. The vehicle power supply integrates CAN communication which can make communication with the upper computer through the control chip TMS320F28035. On the other hand TMS320F28035 can also achieve control logic of the switches, set the dead zone, and phase shift angle between the leading bridge arm and lagging bridge arm [5-6].

### 4. Auxiliary Power Supply Design

A new generation of energy-saving power supply control system must be green quasi-resonant mode to reduce EMI electromagnetic interference, improve efficiency, and reduce standby losses. The UCC28600 power chip is a green power supply control chip of TI's, which solves the above mentioned requirements by special technology. It uses a unique quasi-resonant control method to improve the power efficiency. The quasi-resonant can be divided into four modes, quasi-resonant mode (QRM), discontinuous conduction mode (DCM), frequency modulation mode (FMM) and green mode [7-10].

This paper the auxiliary power supply selects flyback circuit based on the UCC28600 quasi-resonant mode. The schematic is shown in Figure 4.

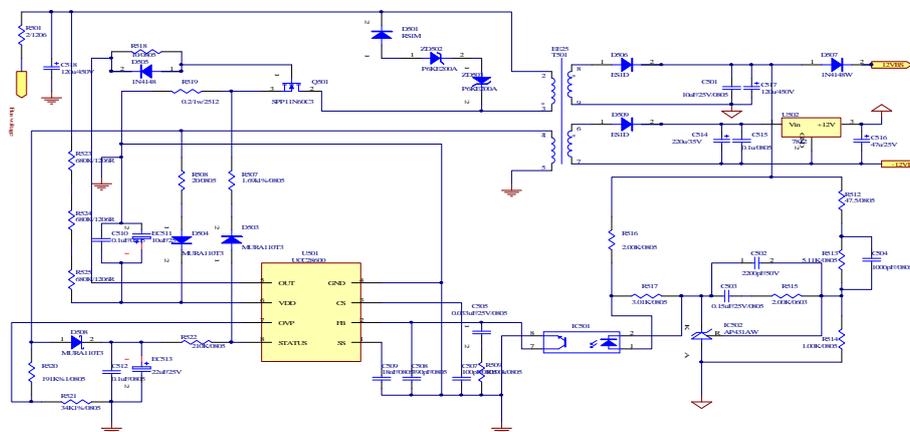


Figure 4. The Schematic of Auxiliary Power Supply

The flyback converter uses UCC28600 as the control chip to obtain multi-mode control, namely adopts corresponding work mode in different load conditions so as to improve the efficiency. The converter realizes electrical isolation between the primary and secondary side, and outputs +12V and +5V. Wherein the +12V is the main output winding used as closed-loop control, in addition +12 V output adopts LC filter to improve the quality of the output voltage so that powers the drive chip, operational amplifier and DSP28035. In order to avoid the output voltage instability caused by cross regulation, the +5 V output uses a three-terminal regulator 7805 to stabilize the output voltage and provides power for the CAN communication.

## 5. Experimental Results

Figure 5 is the principle prototype of phase shift control full-bridge converter.



Figure 5. The Principle Prototype of the Converter

The output is connected with an electronic load. Figure 6 shows the waveforms of the drain-to-source voltage of  $Q_1$  and  $Q_4$ , midpoint voltage of primary side bridge arm  $V_{AB}$ , and the primary current  $i_p$  when  $V_{in}=360V$ ,  $I_o=100A$ . Figure 7 is the waveforms of midpoint voltage of primary side bridge arm  $V_{AB}$ , the drain-to-source voltage of  $Q_{s1}$  and  $Q_{s2}$ , and the primary current  $i_p$  under the same conditions.

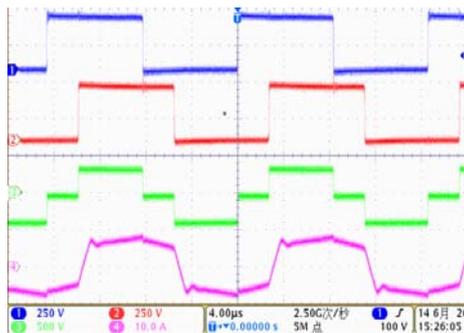


Figure 6. The Waveform of  $V_{DS1}$ ,  $V_{DS4}$ ,  $V_{AB}$ ,  $i_p$  at the Load of 100A

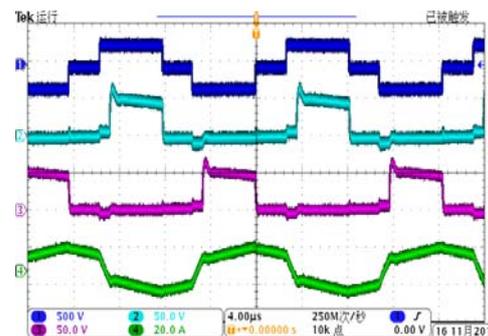


Figure 7. The Waveform of  $V_{AB}$ ,  $V_{QS1}$ ,  $V_{QS2}$ ,  $i_p$  at the Load of 100A

As seen from Figure 6, the voltage and current waveforms are ideal with no large spikes and glitches, namely the main switches of full bridge converter have realized zero voltage switching (ZVS) soft-switching, and the effect is good. In Figure 7 there are some oscillation peaks on the secondary rectifier, which is the consequence of its hard-switching. The specific reason is the resonance between transformer leakage, line parasitic inductance and junction capacitance of secondary rectifier. During the experiment, joins the RC absorption as parameter

optimization which makes the rectifier voltage spikes and parasitic oscillations effectively suppressed.

From channel 1, 2 in Figure 8 and Figure 9, we can see that when the drive voltage rises from negative to positive, the drain-to-source voltage has fallen to zero already. The anti-parallel diode has been conducting, at this time the switch is turned on, this shows that phase shift full bridge converter can realize the ZVS of the leading bridge arm and lag bridge arm [11-12].

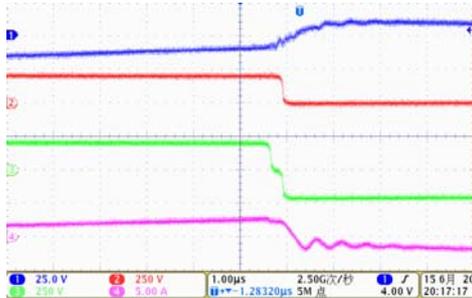


Figure 8. The Waveform of  $V_{GS}$ ,  $V_{DS}$  of the Leading Bridge Arm

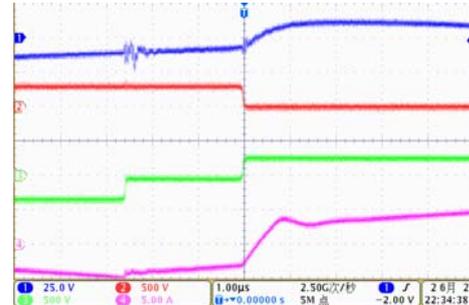


Figure 9. The Waveform of  $V_{GS}$ ,  $V_{DS}$  of the Lag Bridge Arm

Figure 10 shows the efficiency curve within the scope of the whole load range, and the input voltage of the phase shift control full bridge converter is 300V and 400V.



Figure 10. The Efficiency Curve of the Phase Shift Full Bridge Converter

From efficiency curve in Figure 10 we can see that for the same input voltage, light load has lower efficiency. Along with the increasing of the load, the efficiency increases slowly and reaches the highest point at 70A with the efficiency of 96%, then the efficiency drops a little as the load still increases. Light load has lower efficiency due to the converter inherent loss and hard switching state of the converter. With the increasing of the load, soft-switching can be realized; meanwhile the proportion of converter inherent loss of the total power is reduced, so the efficiency will increase slowly. When the load is 70A, there will be a maximum efficiency. As load increases, the efficiency declines, because when the load is heavier, the main influence factor of converter efficiency turns from switching loss into conduction loss. With heavier load, conduction loss will be greater, thus affecting the efficiency.

At the same load, along with the increasing of the input voltage, transformation efficiency will decrease, that is because when input voltage is higher, in order to maintain the output voltage constant, the duty ratio will be relatively small, and in the whole cycle, the proportion of energy transmission time is small as a consequence [13-14]. What's more, the

time of primary current in natural fly-wheel state will be more, and the power in primary side will not transfer to the secondary side during this time, which brings a lot of circulation loss. Therefore, to improve the transformation efficiency, the effective switching duty ratio in the whole input voltage range must be large enough.

## 6. Conclusion

This article researches on DC power supply system of pure electric vehicle. On the basis of principle analysis, an experimental platform has been set up, then completed the system debugging, and finally the waveform and experimental results have been analyzed and summarized.

This converter integrates over-voltage, over-current and over temperature protection, has certain shock resistance and good EMI compatibility. It also uses soft-switching, which bring about 96% conversion efficiency; digital control chip DSP28035 with small volume and cheap price can achieve fast, flexible and intelligent control of the system. Variable auxiliary power control modes are used so as to save energy, improve efficiency and realize the green control. In conclusion, the whole vehicle power supply system has advantages such as environmental friendly, high efficiency, digital and intelligent.

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