Proceedings of the 2023 International Conference on Mechatronics and Smart Systems
DOI: 10.54254/2755-2721/28/20230052

Application of DC-DC power module in electric vehicle system

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Abstract. DC-DC power module has been increasingly widely used in car manufacturing industry and studied by scientists due to its crucial role in electric vehicles. It has two major functions. One is to provide electric power that motivates the power steering system, air conditioning, and other auxiliary equipment; the other is to operate in a hybrid electric source system by connecting with super-capacitors in series in a circuit, which performs a function of regulating power source output, as well as stabilizing the DC voltage bus. This review aims to investigate the fundamental principle of DC-DC converter, to comprehensively review the different types of DC-DC power modules and their characteristics, as well as their advantages and limitations. In addition, to discuss the major challenges existing in this system currently, and the potential it has for future developments, which refers to the power output efficiency of the system when it is applied in electric vehicles. Finally, to demonstrate some real-life applications of this module, the representative examples of firms successfully applying this power module into production. This paper has a guiding significance for acknowledging the current state of development of DC-DC power modules in the electric vehicle system, and for studying some related research fields.

Keywords: DC-DC converter, electric vehicle power system.

1. Introduction

In recent years, there has been an increasing amount of discussions and concerns about the gradually serious environmental issues. Based on the target of reducing manufacturing pollution and harmful gas

DOI: 10.54254/2755-2721/28/20230052

emission, the world is demanding more energy-efficient, environmental-friendly, non-polluting vehicles [1].

According to a report released by the Energy Information Administration (EIA) in 2016, the energy expended on transportation systems took up 55% of the world's total energy consumption [2]. Since the harmful gases generated from the internal combustion in car engines, such as nitrogen oxides, sulfur dioxide, and carbon unburnt hydrocarbons, are the main contributors to acid rain, photochemical smog, and the greenhouse effect, automobile manufacturers are currently aiming to apply renewable energy-based electric propulsion.

Among the challenges automakers are facing right now, using renewable energy sources like fuel cells (FCs) to supply electric vehicles is a significant one to be dealt with. FC is a clean, cost-effective, efficient type of renewable energy source, which can convert hydrogen into electrical energy. In order to match FC and electric vehicle's energy levels, a DC-DC converter is needed in the system, which processes the advantages of good conversion rate, low semiconductor stress, ripple-free input current, and high efficiency [2].

A DC-DC converter is a category of electronic circuit that converts a direct current (DC) voltage from one level to another level, while keeping the polarity of the voltage unchanged. This converter typically includes an input voltage source, a switching element, and an output voltage filter. It may also contain additional components such as inductors, capacitors, and diodes for the purpose of improving the efficiency, stability, and performance of the circuit. For example, some DC-DC converters are designed to have over-temperature protection and fault detection systems, which makes it more reliable over a wide range of operating conditions and environments in real-life applications.

Different types of DC-DC converters are designed to meet different voltage switching requirements. For instance, a Pulse-Width Modulation (PWM) boost converter is a fundamental type of DC-DC circuit that steps up the voltage of the input signal, which makes it suitable for various applications in products ranging from low-power portable devices to high-power stationary applications [3], such as in battery charging, LED lighting, and motor control. This module is widely used due to its low number of elements, which is advantageous for simplifying modeling, design implementation, and manufacturing [3]. Thus, the application of DC-DC power modules in electric vehicle systems is crucial and significant.

The remainder of this article is as follows: The fundamental principle of DC-DC power module as well as its typical categories in Section 2. Introduction of the three component modules of DC-DC power system in Section 3. In Section 4, the challenges DC-DC converter faces when it is supplying power to electric vehicle systems. The development status of this module at domestic and abroad in Section 5.

2. The difference in circuit topology

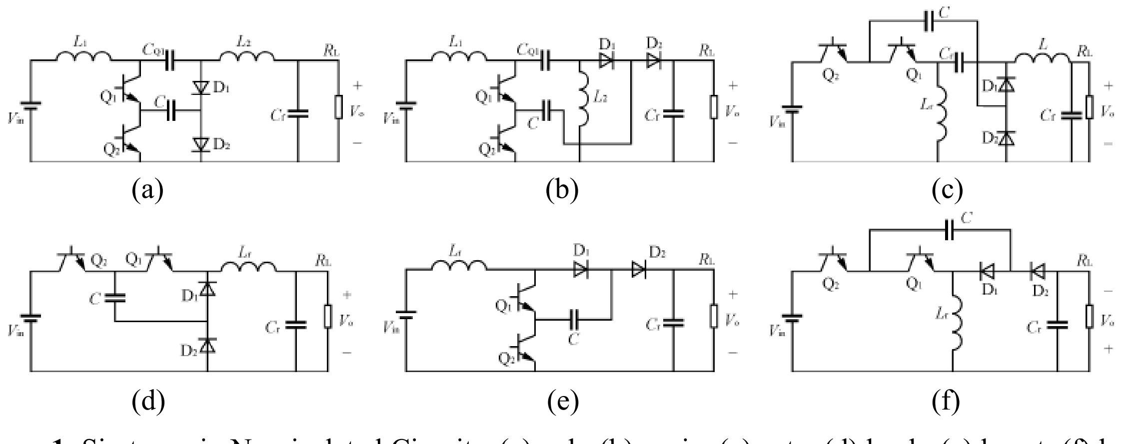

Figure 1. Six types in Non-isolated Circuits. (a) cuk; (b) sepic; (c) zeta; (d) buck; (e) boost; (f) buck-boost.

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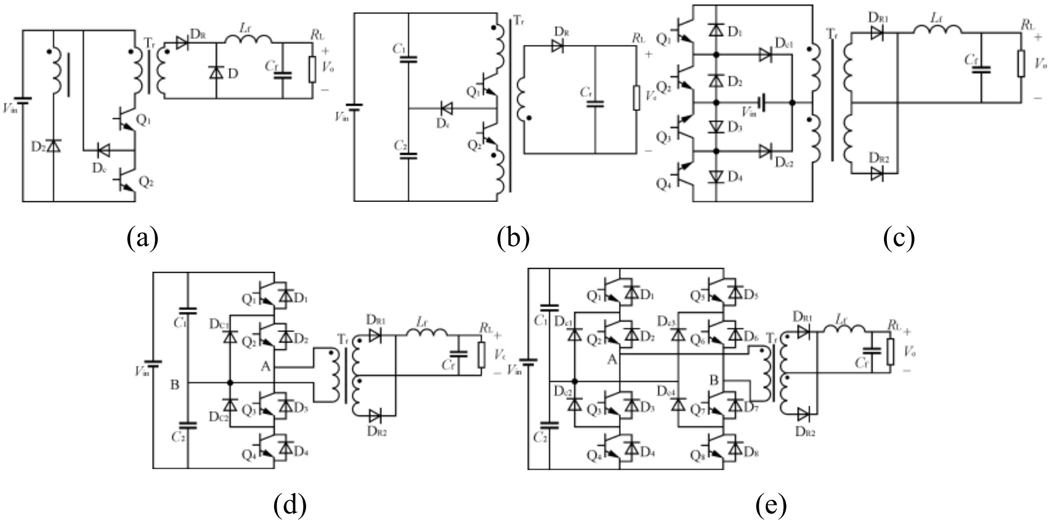

Figure 2. Five types in Isolated Circuits. (a) forward; (b) flyback; (c) push-pull; (d) half-bridge; (e) full-bridge.

Among all kinds of DC/DC available at the market, we can roughly divide them into two groups: Isolated circuits and non-isolated circuits, and in each group, there are also some different principles in each circuit. Figure 1 shows six different topologies in circuit topologies in Non-isolated Circuits, and figure 2 shows five different topologies in Isolated Circuits.

3. Development status of DC/DC at domestic and abroad

In 2013, Xiaocheng Jing et al. proposed a fixed frequency adaptive on-time DCDC converter with fast transient response and high light-load efficiency. When the converter operates in both continuous and discontinuous conduction modes, its on-off time is controlled by the frequency locking loop adaptively, so that the switching frequency tracks the reference frequency throughout the operating range, with an error of less than 0.5%. In addition, the frequency hopping technology with predictable noise spectrum used in the circuit can improve the efficiency of the converter at light loads.

In 2015, Southern University of Science and Technology proposed a BuckBoost converter with single-inductance multiplex output, which solves the load imbalance problem of different channels by means of a phase-locked loop and automatic phase allocation technology, so that the locking time of inductance current is short enough and higher efficiency is achieved by minimizing the average inductance current. In terms of improving the transient response speed, by combining the converter with the all-channel controller, the transient response time can be reduced without reducing the efficiency.

In 2017, JiannJong Chen et al. proposed a novel Buck converter with dynamic slope compensation technology. When the converter is interfered with, the proposed dynamic ramp technology combined with the optimal damping control circuit can achieve rapid stability within one cycle and accelerate the transient response when the load current jumps. The measured results show that the transient response time of the converter is only 2μs when the load current jumps between 50mA and 500mA.

In 2018, LiQinqin et al. from Xidian University proposed an adaptive current threshold determination scheme under load change. When the converter is under light load, the output voltage ripple can be reduced while the partial on-off loss caused by inductor current ripple can be reduced, so as to improve the efficiency of the converter under light load.

In 2020, YuhShyanHwang proposed a Buck-type DCDC converter with low stray noise and fast transient response combined with a second-order continuous-time E-O modulator. The E-△ modulator has the advantages of oversampling and noise shaping. The converter maintains the high efficiency, low noise and low ripple of the traditional switching converter, while the output harmonic energy is lower and the transient response speed is faster [4].

4. The future development trend

Nowadays, mobile terminals, automotive electronics, and communication equipment are widely used as an efficient and highly integrated DC-DC converter as a power management system. Switching power supply has taken up a large share of the power management market. Well-known semiconductor companies such as LT, TI, MAXIM and ST have launched their own monolithic integrated power supply products with excellent performance and high reliability. In the next very long period of time the following aspects will still be the main development direction of switching power supply:

4.1. High frequency

The frequency of the switch increases, and the energy of a guide cycle is reduced by the amount of energy transferred to the output, which can effectively reduce the size of the storage and transmission energy components, and also improve the dynamic characteristics of the circuit. The reduction of storage element and power adjustment tube size is the fundamental means of reducing the power volume of the switch, and the reduction of the power volume of the switch power volume will be a good way to reduce the manufacturing cost of the chip and reduce the power consumption and packaging difficulty of the chip.

4.2. High efficiency

Into the 21st century, the energy problem has attracted more and more attention and become one of the focus of the world. Energy conservation and environmental protection have come into People's Daily life. How to use energy efficiently has become a problem that scientists strive to explore and solve. Therefore, it is necessary and important to improve efficiency. As the efficiency of switching power supply is between 80% and 90%, with the progress of technology, power supply designers continue to explore new ways to improve efficiency, such as soft switching circuit design in chips, the use of synchronous rectification technology, output self-lifting pressure technology and so on.

4.3. Digitalization

The digital control of DC-DC converter has been studied deeply. The traditional analog control mode is controlled by analog signal, the circuit response is slow and the efficiency is not high. The digital control method is based on the smaller process size, can complete the complex logic control, easier to integrate with other digital circuit modules 51. In the future, the market prospect of digital controlled power supply is very considerable.

4.4. Highly integrated

With the progress of science and technology, the miniaturization and multi-function of mobile terminal products have become particularly important, which requires a highly integrated power chip inside. As early as 1992, Power Integration has been powering the periphery

5. The principle of DC/DC converters

DC/DC converters convert the input DC voltage to the output DC voltage and can convert the voltage to either boost or buck. DC/DC converters are switching power supplies. It modulates the input DC voltage into a controllable square wave by means of a control circuit, and then connects the energy storage devices, inductors and capacitors, in different ways to convert the energy.

Depending on the connection of the inductor in the topology, three different functions can be realized: buck, boost, and lift.

DC/DC converters are classified as Buck converters, Boost converters, Buck-Boost converters and SEPI converters. Buck converters and Boost converters can realize buck and boost functions, respectively, while Buck-Boost converters and SEPI converters can realize both boost and buck functions. Figure 3 shows all these converters, including Buck converters, Boost converters, Buck-Boost converters and SEPI converters.

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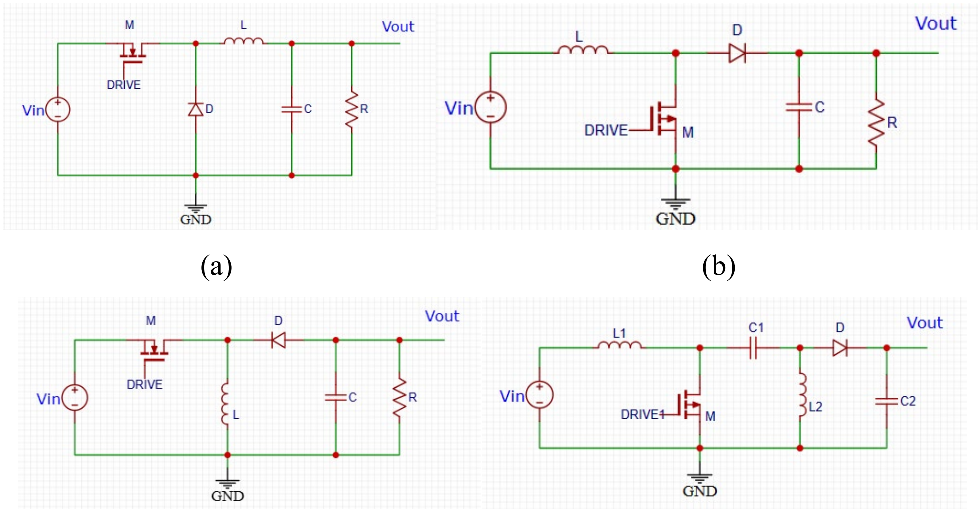

(a) (b)

(c) (d)

Figure 3. The four basic topologies of DC/DC converters: buck converters, boost converters, buck-boost converters and SEPI converters.

Analyzing the topologies of the converters, one can start with the characteristics of the inductor. Since the current on the inductor does not change abruptly, the rate of change of the inductor current follows the equation described by equation (1):

$$V = L \cdot \frac{\Delta I}{\Delta t} \tag{1}$$

Where, represents$V$the voltage difference across the inductor, is the$L$value of the inductor $\frac{\Delta I}{\Delta t}$ and is the rate of change of the inductor current.

The switching process of the DC/DC converters corresponds to the charging and renewing process of the inductor, the charging time of the Δt_{ON} converter is, and the Δt_{ON} renewing $T = \Delta t_{ON} + \Delta t_{ON}$ time$T$is, and, is a clock cycle. The inductance equation of the charging phase and the inductance equation of the renewing phase are obtained by equation (1);

$$V_{ON} = L \cdot \frac{\Delta I_{ON}}{\Delta t_{ON}} \tag{2}$$

$$V_{OFF} = L \cdot \frac{\Delta I_{OFF}}{\Delta t_{OFF}} \tag{3}$$

where and V_{ON} represent V_{OFF} the voltages at the terminals of the inductor in the charging and renewal phases, ΔI_{ON} respectively, ΔI_{ON} and represent the variation of the inductor current in the charging and renewal phases, respectively. Taking the premise that the starting and ending values of the inductor current do not change in one cycle, the volt-second balance theorem is obtained by combining equation (2) and equation (3), and the product of the voltage and duration on the inductor is the volt-second, D and the duty cycle represents the percentage of on-time in one cycle.

$$\Delta I = \frac{V_{ON}}{L} \cdot t_{ON} = \frac{V_{OFF}}{L} \cdot t_{OFF} \tag{4}$$

$$D = \frac{\Delta t_{ON}}{T} \tag{5}$$

The following analysis of Buck-type topology, Boost-type topology, Buck-Boost-type topology, and SEPIC-type composite topology.

In the Buck topology shown in Figure 3(a), ignoring the on-off voltage drop of the continuity diode, $V_{ON} = V_{in} - V_{out}isV_{OFF} = V_{out}$ obtained according to the volt-second balance theorem of equation (4):

$$(V_{in} - V_{out}) \cdot D \cdot T = V_{out} \cdot (1 - D) \cdot T \tag{6}$$

After simplification, we obtain the relationship between input and output voltage and duty cycle D:

$$V_{out} = D \cdot V_{in} \tag{7}$$

In the Boost topology shown in Figure 2(b) is $V_{ON} = V_{in}$ obtained $V_{OFF} = V_{out} - V_{in}$ according to the volt-second balance theorem as follows

$$V_{in} \cdot D \cdot T = (V_{out} - V_{in}) \cdot (1 - D) \cdot T \tag{8}$$

After simplification, the input and output voltages are obtained as aDfunction of duty cycle

$$V_{out} = \frac{1}{1 - D} \cdot V_{in} \tag{9}$$

In the Buck-Boost topology shown in Figure 3(c), unlike the Buck and Boost topologies, the Buck-Boost topology has the opposite polarity of the output voltage and the input voltage, $V_{ON} = V_{in}$ and $V_{OFF} = -V_{out}$ is obtained from the volt-second balance theorem:

$$V_{in} \cdot D \cdot T = -V_{out} \cdot (1 - D) \cdot T \tag{10}$$

After simplification, the relationship between input and output voltages and D duty cycle is obtained 0:

$$V_{out} = -\frac{D}{1 - D} \cdot V_{in} \tag{11}$$

The SEPIC (Single Ended Primary Inductor Converter) composite topology is shown in Figure 3(d). Different from the first three basic topologies is that it has two inductors $L1$, $L2$. When the field$M$effect tube is on, the input $L1$ voltage, inductor and$M$field effect tube form a $C1$ pathway, $L2$ capacitor, inductor and M field effect tube form another pathway, at$L1$this$L2$time the inductor, energy storage. Analysis in the field effect M tube conduction, inductance and $L1$ voltage $L2$ values at both V_{L1_ON} ends V_{L2_ON} and have:

$$V_{L1\_ON} = V_{in} \tag{12}$$

$$V_{L2\_ON} = V_C \tag{13}$$

When the field M effect tube is not on, $L1$ the $L2$ inductor and in the stored energy D flow through the diode to the output. At this time, the analysis of the two inductors and the voltage value at both ends V_{L1_OFF} of V_{L2_OFF} the inductor can be obtained:

$$V_{L1\_OFF} = V_C + V_{out} - V_{in} \tag{14}$$

$$V_{L2_{OFF}} = V_{out} \tag{15}$$

In the above four equations, all omitted the diode D and the field M effect tube voltage drop. And V_{in} is the input voltage source, V_C is the $C1$ voltage across the capacitor V_{out} is the voltage value at the output. For the inductor, $L1$ according to its voltage at both ends of the field-effect tube on and M off, respectively, Write the expression for the duty cycle D1 according to V_{L1_ON}, V_{L1_OFF} as.

$$D1 = \frac{V_{L1\_OFF}}{V_{L1\_ON} + V_{L1\_OFF}} = \frac{V_C + V_{out} - V_{in}}{V_C + V_{out}} \tag{16}$$

Similarly, for an inductor, $L2$ according to the value of the voltage at its terminals when M the FET is on and off, V_{L2_ON} respectively, V_{L2_OFF} and write the expression of duty cycle D2 as:

$$D2 = \frac{V_{L2\_OFF}}{V_{L2\_ON} + V_{L2\_OFF}} = \frac{V_{out}}{V_C + V_{out}} \tag{17}$$

And the duty cycle D1 and D2 are equal, so from equations (16) and (17) can be obtained:

$$V_C + V_{out} - V_{in} = V_{out} \tag{18}$$

can be derived as:

$$V_C = V_{in} \tag{19}$$

Putting equation (19) into either equation (16) or equation (17) yields the same D as:

$$D = \frac{V_{out}}{V_{in} + V_{out}} \tag{20}$$

Continuing the derivation of Eq. (20), we obtain:

$$V_{out} = V_{in} \times \frac{D}{1 - D} \tag{21}$$

Observing equation (20), it can be seen that for the composite SEPIC-type topology, its duty cycle is the same as that of the classical single-inductor buck-boost topology. Again, when the duty cycle 0<D<0.5; when 0.5<D<1. $V_{out} > V_{in}$ This is how the SEPIC-type compound topology works, which can be implemented, $V_{out} > V_{in}$ or $V_{out} < V_{in}$. $V_{out} = V_{in}$ It is worth noting that it has one difference with the buck-boost structure which can also be boosted, in that the SEPIC-type compound topology is positive polarity, while the buck-boost is reverse polarity. This is mainly due to the two inductors and a coupling capacitor $C1$ in the SEPIC, as well as the inductor-capacitor characteristics 0.

Since the D duty cycle varies from 0 to 1, the voltage conversion function can be seen from the input-output relationship of the above topologies.

6. Components of DC-DC system

6.1. Main circuit (power module)

The main circuit controls the power output of the system and is the main body of the whole system. Fig.1 is the main circuit topology of a typical full-bridge DC-DC converter. In the figure, Vin is the input voltage, and an ideal voltage is obtained at the output terminal after passing through the DC-DC circuit. Figure 4 shows the Full-bridge DC-DC main circuit topology.

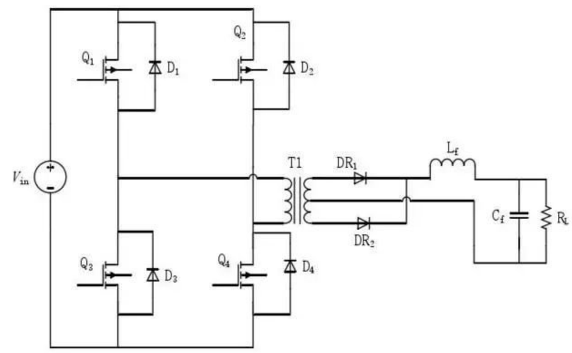

Figure 4. Full-bridge DC-DC main circuit topology.

6.2. Driver module

The control chip outputs four PWM driving signals, but for the four power switch tubes, these signals are not enough to drive. Therefore, a switching power supply is generally equipped with a driving circuit to complete the driving task. Drive circuits can be divided into different types, mainly including the following three types:

6.2.1. Direct coupling type. The PWM drive signal output by the direct-coupled drive circuit drives the power switch tube through an amplifying circuit composed of two triodes, but this driving method can not isolate the control part from the main circuit.

6.2.2. Pulse transformer coupling type. The pulse transformer coupling drive circuit is based on the direct coupling type with a pulse transformer added to isolate the control circuit from the main circuit. The main disadvantage of the structure is that the process of designing and manufacturing the transformer is relatively complicated.

DOI: 10.54254/2755-2721/28/20230052

6.2.3. Driver circuit of the driver chip. The production of driver chips is to drive power switch tubes more conveniently. The driver chips developed by many companies can output larger drive power to drive switch tubes. In recent years, the development of chips tends to be miniaturized, and various packaging forms are used.

6.3. Control module

The control module can collect voltage signals and current signals input and output from the main circuit, the voltage and current signals of the output filter inductor, and the peak current signal of the power switch tube, etc., various types of feedback closed-loop control systems are formed by comparing the given reference signals with these signals, so as to control the opening and closing of the power switch tube of the main circuit, adjust its output voltage and current stability, and also play a protective role in the case of overvoltage and overcurrent [6]. Figure 5 is the system block diagram of the control mode.

The feedback of the main circuit mainly includes voltage control mode and current control mode, and the current control mode can be divided into two modes: peak value and average value. The equivalent block diagrams of voltage and current control modes are shown in figure 6 and figure 7, respectively.

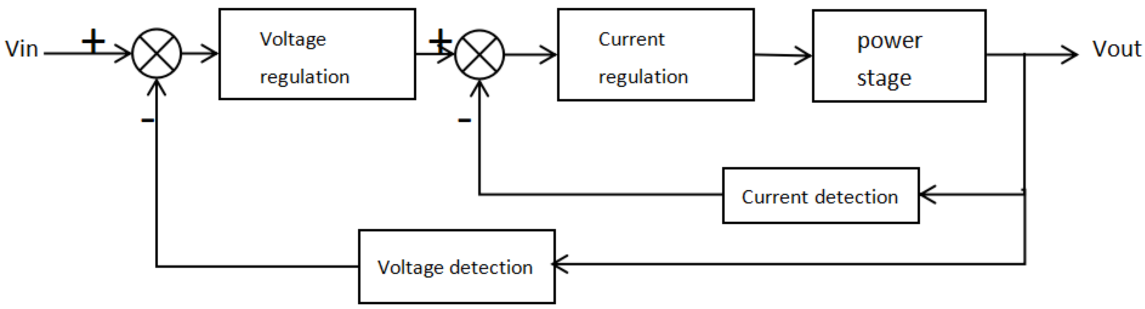

Figure 5. Control mode system block diagram.

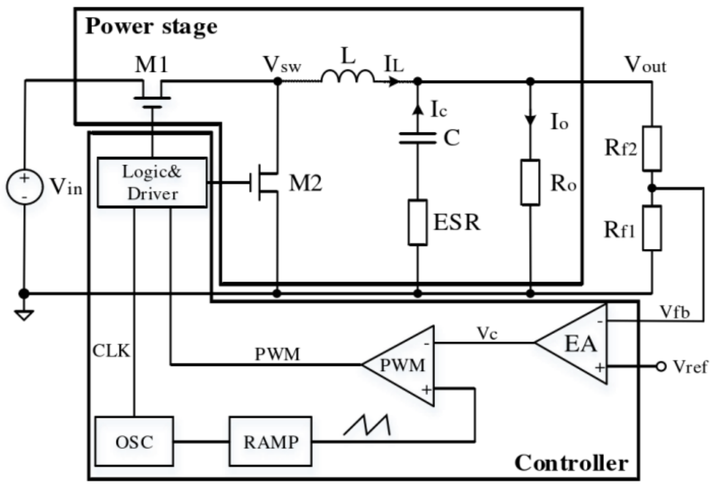

Figure 6. Equivalent block diagram of voltage control mode [7].

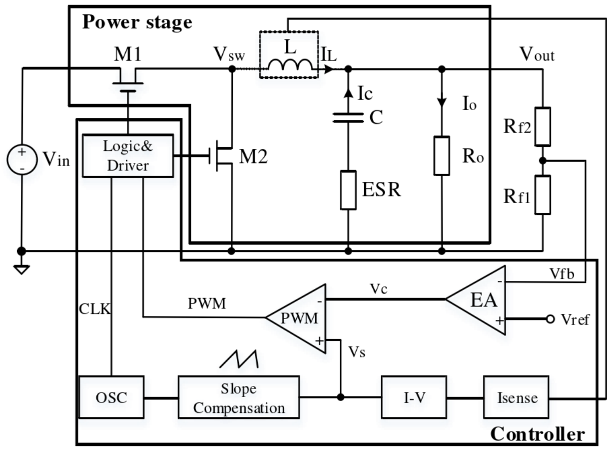

Figure 7. Equivalent block diagram of current control mode [7].

6.3.1. Voltage control mode. The voltage control mode belongs to the single-loop feedback mode, it adopts voltage feedback and uses the output voltage to correct, and outputs PWM wave after comparing the voltage error signal with the reference voltage. When a clock signal arrives, the PWM wave changes from low level to high level, indicating that the switch signal is turned on. During this clock cycle, the PWM wave may be reversed, indicating that the switch signal is turned off. The moment of conversion is determined by the comparison of the voltage error signal and the sawtooth wave. The design and application of the voltage control mode are not complicated, but the voltage control mode does not control the output current, so there may be certain errors. The output voltage is filtered by the inductor and capacitor first, and is affected by the delay effect, resulting in insufficient dynamic response. Figure 6 is the equivalent block diagram of the voltage control mode.

6.3.2. Peak current control mode. There are some differences between the peak current control mode and the voltage control mode. It is characterized in that the voltage error signal is compared with a triangle wave representing the inductor current value, thus replacing the sawtooth wave in voltage control mode. In one clock cycle, the PWM wave first goes from low to high, which represents the on signal. When the detected peak current signal is equal to the voltage error signal, the PWM wave signal is turned off, so that the pulse width of the PWM wave can be controlled. Assuming that the peak value of the inductor current increases suddenly, the time that the switch is on becomes shorter, thereby reducing the peak current. The peak current control mode directly samples the inductor current, and reflects the change of the input voltage through the change of the current. Therefore, this method has good feed-forward compensation and can respond quickly to the change of the input voltage, but the problem is that the instantaneous current of the inductor can not represent the average current situation.

6.3.3. Average current control mode. The average current control mode is a kind of double-loop control mode. After the output voltage is sampled, it is compared with the current sampling signal after passing through the error amplifier, and then the voltage signal is output after passing through the error amplifier of the next stage, and finally compared with the sawtooth wave to obtain the duty cycle of the PWM wave. That is, the output signal of the voltage loop is used as the reference current to compare with the feedback signal of the inductor current, and the error amplifier can be set to average some high-frequency components of the input current, the output processed current is compared with the sawtooth wave generated by the chip and then an appropriate PWM waveform is output. The average current control mode has all the advantages of the peak current control mode, but also ensures a high loop gain, which can remove the error of the peak value relative to the average value and collect more accurate inductor current signals.

7. Application of DC-DC converter in on-board charger of electric vehicle

For most of on-board charger, bidirectional DC-DC converters always be the first choice. The characteristics of this kind of converter are to make the energy achieve two-way flow. Based on Buck circuit and Boost circuit, we can easily gain the Non-isolated basic topology [8]. And if we add AC link in the DC converter circuit, we can now gain the Isolated bidirectional DC-DC converter [9], which could make sure the energy two-way flow.

7.1. Non-isolated converter

In actual production application, we do not actually use this kind of. Even though it has the advantages like small size, safe convenient installation, high efficiency and low cost, it still has much more problems especially in operational efficiency issues. Figure 8 is a basic non-isolated BDC, it can Realize basic two-way flow of energy. But because of the presence of MOSFET body diodes, when it runs CCM (continuous conduction mode) under high voltage, there are serious reverse recovery problems in the circuits [10].

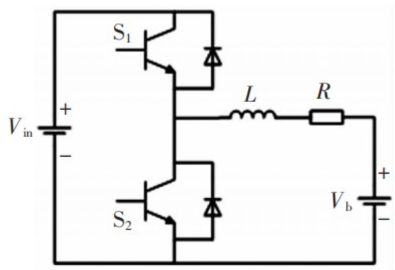

Figure 8. Basic non-isolated BDC.

7.2. Isolated converter

We usually divide the isolated converter topology into voltage-fed and current-fed [11].

7.2.1. Voltage-fed. Dual active full-bridge converter is a kind of more mature and widely used converter topology, which can easily realize ZVS (zero voltage switching) through phase-shift control to improve the power efficiency [12]. But there is a significant disadvantage, during the short time of current commutation the polarity of current and voltage is opposite. So there will be a resonant power between voltage source and inductors called reactive power, which is adverse to the efficiency of circuit operation [13]. To solve this kind of problems, many scholars did some improvements of traditional control method for double active full bridge circuit. There is a method called extended phase-shift control [14], which had achieved good results. And there is another method called digital control method based on dual phase-shift control [15]. But if we run it under low power condition, the loop current will produce to limit the power. To solve this problem, adopting phase-shift control Hybrid control method combined with PWM control could be an effective method [16].

7.2.2. Current-fed. There is a large inductor in this kind of DC-DC converter, so it is unnecessary to add excess magnetic element to form boost circuit. When we use it in the charging system, the voltage will has a pretty high conversion ratio [17]. But because of the existence of transformer leakage inductance, so the switch tube will may be subject to large voltage impulse [18].

There is one significant method to decrease voltage impulse. An improved Current source topology based on dual half bridge [19]. It moves the end of the inductance not connected to the power supply to the middle of the bridge arm by adopting phase-shift control Control method combined with PWM control, as figure 9.

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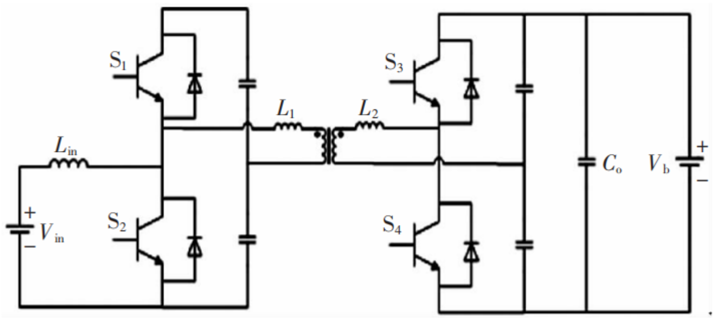


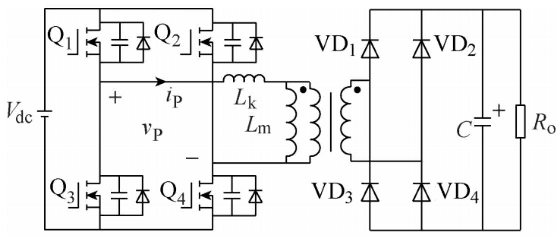
Figure 9. An improved dual half-bridge current-fed BDC.

There is another method, that is using the principle of interleaved connection of circuits to improve the structure of topology. When the power is charging, it can implement input-parallel and output-series. And when the power is discharging, it can implement input-series and output-parallel [20].

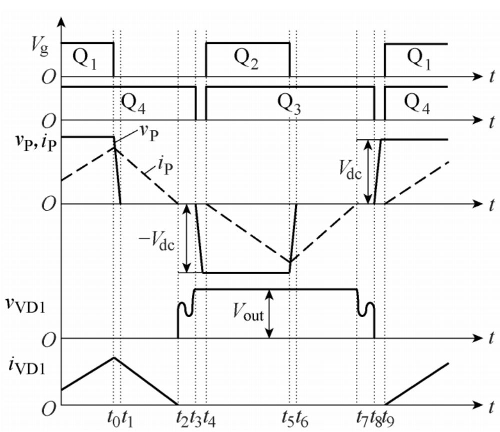
7.3. Realize efficient operation of DC-DC converter

To realize efficient operation of DC-DC converter, there are basically two wildly used methods. The first one is improving the structure of circuit topology, which we have introduce some of these before. And the other one is to change the drive mode of the converter.

7.3.1. Back-edge pulse width modulated full-bridge DC-DC converter. Because of the self deficiency of DC-DC converter, some scholars put forward Back-edge pulse width modulation technology [21-24]. Firstly ,we give the converter circuit topology and steady-state working waveform as figure 10.



(a) Main circuit



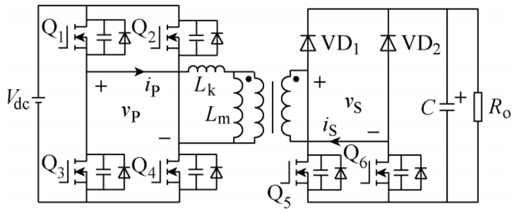
(b) Main working waveform

Figure 10. Topology and waveforms of full-bridge DC-DC converter with trailing edge pulse width modulation.

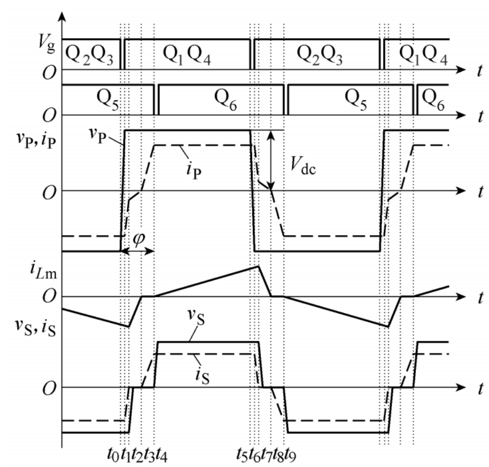
Among this topology, Q3 and Q4 are driven complementarily by 50% duty cycle, Q1 and Q2 are driven in PWM mode. If we use voltage driven rectifier as converter, we will face to the problem of DC-DC converter still has. So, this drive mode is usually combined with current-driven rectifier. Now, when we run this converter under Continuous Conduction Mode, all switching devices at the primary side of transformer can realize ZVS.

7.3.2. Secondary phase-shifted full-bridge DC-DC converter. When we run 50% duty cycle to PWM controlled full-bridge converter, it can achieve high conversion efficiency. But at the same time, the output power of the converter is uncontrolled. Based on this problem, some scholars use the control technology of SPS (Secondary-side Phase Shift) [23-28]. The output power can be adjusted by controlling the phase shift of the switch at the primary and secondary sides of the converter at different times.

A novel about ZVS DC-DC converter for high power applications firstly proposed SPS control scheme [25]. After that, some researchers apply the basic idea of SPS to the full-bridge DC-DC converter [26-28]. A report further summarizes a family of SPS-controlled full-bridge soft-switching converters, figure 11 show the typical circuit topology and the main working waveform [29].



(a) Main circuit



(b) Main working waveform

Figure 11. Topology and waveforms of SPS-FB DC-DC converter.

As we can see in Fig.4, the reason why this converter does not have the circulation problem is current decays and resets rapidly under the action of input power supply and load. It is different from PPS, field current of converter does not change with load under this kind of control mode. So we can use the field current to achieve ZVS operation of converter in a wider load range [30]. At the same time, this kind of converter can still use current-driven rectifier, which is no need to consider reverse recovery problems. What's more, this kind of converter have better output voltage gain characteristic, especially be suitable for power battery pack. At present, the maximum efficiency of this kind of converter can reach 96% [27].

DOI: 10.54254/2755-2721/28/20230052

8. Conclusion

The charging operation characteristics of the battery pack make the operating status and efficiency of the DC-DC converter in the on-board charger change in a wide range, which brings great challenges to the design of the converter. Focusing on the application of DC-DC converters in vehicle power supply systems, this paper first introduces the basic isolated and non-isolated circuit topologies, and reveals the development of DC-DC converters in vehicle power supply systems. On this basis, the composition of the DC-DC system is summarized from the main module, drive module and control module. This paper analyzes and summarizes the practical problems of how to improve power supply efficiency by using DC-DC converters. Finally, this paper shows the shortcomings in the efficiency evaluation and design process of the converter, and give a new idea for the integrated design and control of the converter system.

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