Dual Buck Inverter with Series Connected Diodes and Single Inductor

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***Abstract*—In a DC-AC system, some problems may threaten the reliability of the whole system, such as the shoot through issue and the failure of reverse recovery. Some methods are proposed to improve the reliability of the converters. The dual buck inverters can solve the above problems without adding dead time but the dual buck topology has a main drawback of low magnetic utilization which increases the volume and weight of the system. This paper firstly summarizes the traditional dual buck topologies including a kind of single inductor dual buck inverter which can make full use of the inductance. Then a method to improve the reliability of the MOSFET inverter is proposed. A kind of novel dual buck inverter with series connected diodes and single inductor is introduced. The novel inverter retains the dual buck topologies' advantage of high reliability and can make full use of the inductance. Also, compared to the traditional single inductor dual buck topology, the controlling strategy of the proposed inverter is simpler. Finally, the simulation and experimental results verified the theoretical analysis.**

Keywords—dual buck inverter; shoot through problem; photovoltaic inverter; leakage current

I. Introduction

The fast development of the clean energy power generation requires the inversion system, especially the inverters, to be more and more reliable. Yet shoot through problem of the power devices is a major threaten to the reliability. As is known, a traditional method to solve the shoot through issue is by setting dead time. However, the dead time will cause a distortion of the output current. Also, during the dead time, the current may flow through the body diode of the switch which can cause the failure of the reverse recovery [1].

For the purpose of solving the above problems, the dual buck topologies are proposed in a lot of research. By combining two unidirectional buck circuits, the dual buck inverters will not suffer the threaten of shoot through problem and the freewheeling current will flow through the independent diodes which can solve the reverse recovery problem of the MOSFET's body diodes. However, the major drawback of the dual buck topologies is the magnetic utilization. Only half of the inductance is used in every working mode. And it will obviously increase the weight and volume of the system [2]-[4].

In order to improve the magnetic utilization of the dual buck inverter, a kind of single inductor dual buck topology was proposed in [5]. Compared with the traditional full bridge inverter, two extra switches are applied in the proposed topology. The single inductor topology can make full use of the inductance, but the conducting loss is largely increased because four switches are flown through during the power delivering modes.

This paper proposed a kind of novel phase leg topology with series connected diodes and single inductor to highly improve the reliability of the inverter, especially for the MOSFET inverter [6]. Applying the phase leg to the single phase inverter, an improved single inductor dual buck inverters are proposed in this paper. The novel topology has the following advantages: firstly, retains the advantages of the traditional dual buck inverters, secondly, makes full use of the inductance, thirdly, the proposed inverter saves two switches compared to the traditional single inductor topology, which makes a lower conducting loss and a simpler controlling strategy. The simulation and experimental results have verified

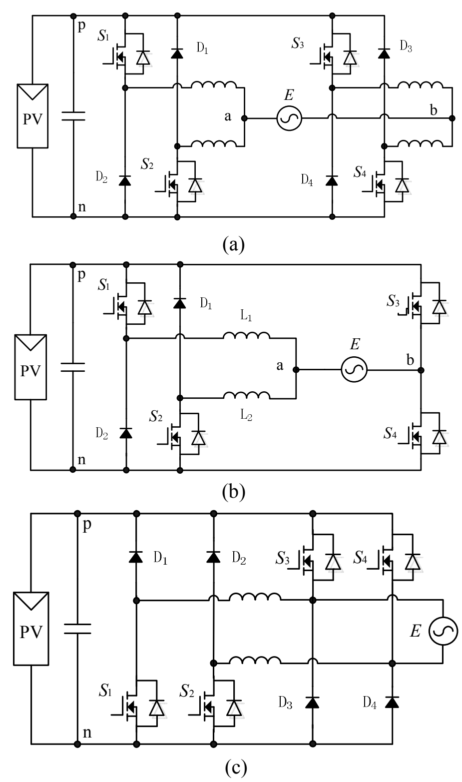


Fig. 1. Traditional Dual buck and dual boost full bridge inverters.

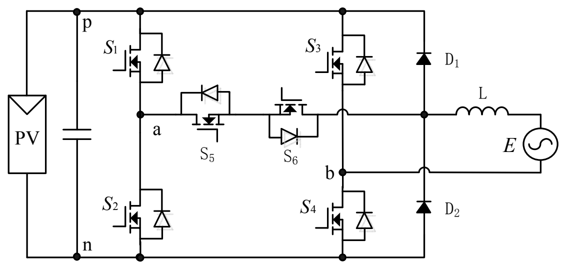


Fig. 2. Traditional Dual buck full bridge inverter with single inductor.

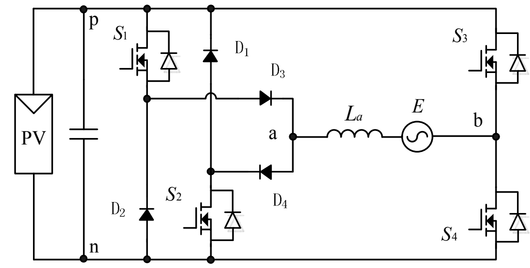
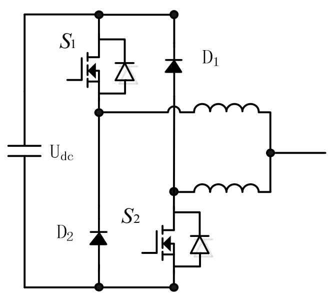
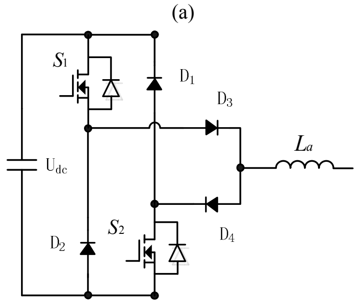


Fig. 4. Proposed dual buck full bridge inverters with single inductor.



(a)



(b)

Fig. 3. (a)Traditional dual buck phase leg (b) proposed dual buck phase legs with series connected diodes and single inductor.

the analysis.

II. Traditional Dual Buck Topologies

Fig. 1 shows the traditional dual buck and dual boost inverters [7]-[8]. The most attractive advantage of the dual buck topologies is the high reliability. Firstly, without adding the extra dead time, the dual buck topologies can solve the shoot through problem. Secondly, compared to the traditional H-bridge inverter, the current will not flow through the body diodes of the switches in the dual buck topologies which means no reverse recovery problem exists in the MOSFET phase legs. Considering the above two aspects, the dual buck topologies can achieve high reliability without the shoot through and reverse recovery issues.

However, the main drawback of the dual buck topologies is the low magnetic utilization. In each power delivering and freewheeling modes, the current only flow through half of the inductance, which means the other half of the inductance is wasted in each working condition. The low utilization of the inductance makes the increasing of the weight and volume for the whole system. To solve this problem, a concept of single inductor dual buck full bridge inverter [5] is proposed. Fig. 2 shows the single inductor topology. The novel topology includes six switches and two diodes. Comparing to the traditional dual buck full bridge inverter, the single inductor topology can save half of the inductance. And the novel topology retains the original advantages of high reliability. Also, there is no need to add the dead time in the high frequency unipolar switching strategy. The inductance can be fully utilized in the single inductor inverter. However, a high level of conduction loss is the main drawback of the novel topology. During the power delivering mode, the current flows through four switches which is a lot more than the traditional full bridge inverters. Besides, compared to the traditional H-bridge inverters, the extra two switches make controlling strategy more complex. And in the dual buck single inductor inverter, the current will flow through the body diodes of the series MOSFET switches which can cause the problem of reverse recovery.

To solve the problem of traditional H-bridge inverter, including the shoot through issue and the reverse recovery of the MOSFET, a kind of dual buck inverter with series connected diodes and single inductor is proposed in this paper. The newly proposed topology retains the advantage of traditional dual buck inverter and solve the problem of low magnetic utilization. Also, the proposed topologies will not invite extra switches which means a simpler controlling strategy compared to the traditional dual buck single inductor full bridge inverter in [5].

III. Highly Reliable MOSFET Inverter With Single Inductor

This section proposes a kind of novel MOSFET phase leg which maintains the high reliability of the dual buck topology and also makes full use of the dual buck's inductance. Fig. 3 shows the traditional dual buck phase leg and the proposed novel MOSFET phase leg. The two inductors in Fig. 3(a) are replaced by two diodes and one inductor just as shown in Fig. 3(b). Applying the proposed phase leg to the full bridge inverter, a novel dual buck MOSFET inverter with series connected diodes and single inductor is proposed then. The novel dual buck inverter is shown in Fig. 4. Compared to the traditional single inductor dual buck inverter in Fig. 2, the proposed topologies save two switches which means a simpler control strategy. Meanwhile, in the power delivering mode, the current of the novel topology only flows through one switch and two diodes which is less than the traditional one in Fig. 2 [5].

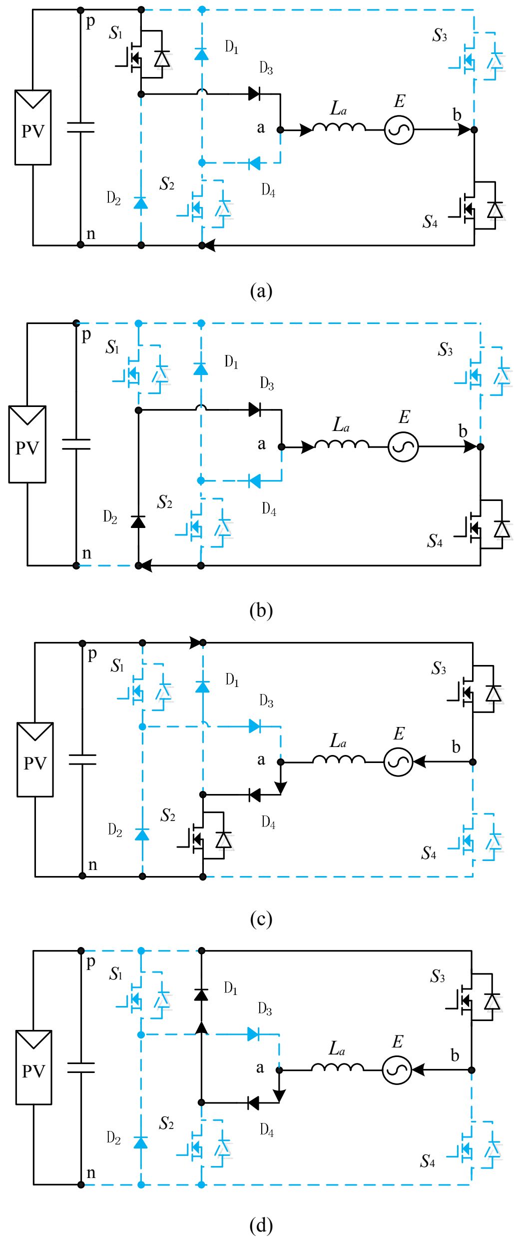


Fig. 5. Four working modes of the proposed dual buck full bridge inverter with single inductor in Fig. 4.

So, the proposed single inductor dual buck topologies have the advantages in the aspect of efficiency, control complexity and system cost and size. The operational principle of proposed single inductor dual buck inverter can be illustrated with four operation modes. Fig. 5 shows the specific current flow paths during the energy transferring modes and the freewheeling modes. A unipolar SPWM strategy is applied to control the four switches of the novel inverter.

A. Operational Principle of the Proposed Inverter

Mode 1: During positive half period, S_1 is modulated in high frequency, while S_4 is always ON. When S_1 and S_4 are on, the current flows through S_1, D_3, grid and S_4 successively.

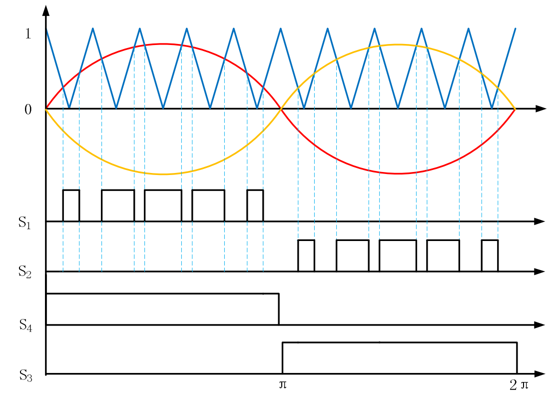


Fig. 6. The switching signals of the proposed inverters.

Mode 2: When S_1 is off, the current flows through D_2, D_3, grid and S_4 successively. As shown in Fig. 5(b), in this freewheeling mode, the diode D_4 prevents the current from flowing through the body diode of S_2, which avoid the failure of the MOSFET’ s reverse recovery.

Mode 3: During negative half period, S_2 is modulated in high frequency, while S_3 is always ON. When S_2 and S_3 are on, the current flows through S_3, grid, D_4 and S_2 successively.

Mode 4: When S_2 is off, the current flows through S_3, grid, D_4 and D_1 successively. As shown in Fig. 5(d), in this freewheeling mode, the diode D_3 prevents the current from flowing through the body diode of S_1, which can also avoid the failure of the MOSFET’ s reverse recovery.

The switching signals of the proposed inverter are shown in Fig. 6. Without the extra two switches of the traditional dual buck single inductor inverter [5] in Fig. 2, the proposed dual buck topology with series connected diodes can achieve the high reliability. No dead time is needed in the high frequency of the switches. Thus, the distortion rate of the output current can be decreased.

B. Analysis of the Common-mode Characteristic

The transformerless photovoltaic (PV) grid-connected system is an important application for the single phase inverter. However, in a transformerless PV system, the fluctuation of the common mode voltage will excite leakage current in the common mode path which may cause the safety problems and

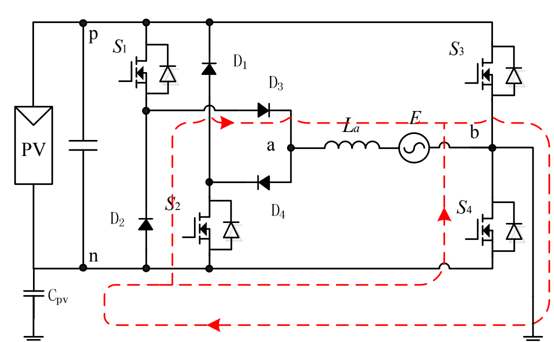


Fig. 7. The equivalent common-mode circuit of the proposed single inductor dual buck inverter.

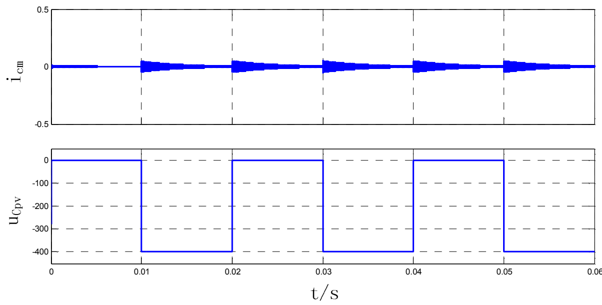


Fig. 8. The simulated common mode waveforms of the proposed dual buck inverters.

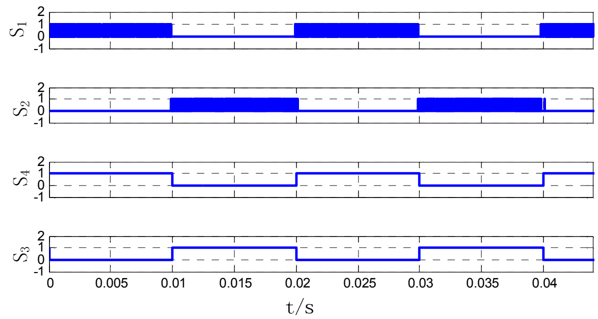


Fig. 9. The simulated switching signals of the proposed dual buck inverters.

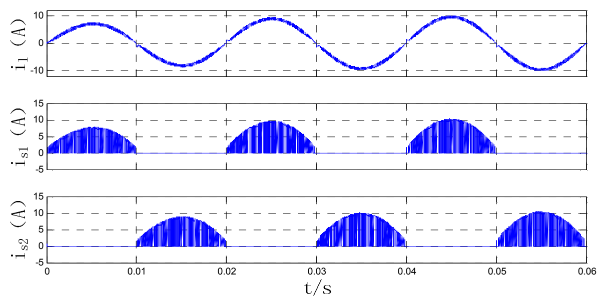


Fig. 10. The filtering current and the switching current of the proposed inverter in Fig. 4.

distort the output current. The equivalent common mode circuit of the proposed inverter is shown in Fig. 7. The red lines represent the flowing path of the leakage current. The value of the leakage current depends on the fluctuating frequency of the common-mode voltage, u_{Cpv} where the C_{pv} represents the equivalent stray capacitance of the PV panel.

As is shown in Fig. 7, in the positive grid period, the upper potential of C_{pv} is equal to the ground. So, the u_{Cpv} is zero in this situation. On the other hand, in the negative grid period, the potential of point p is equal to the ground. Thus, the upper potential of C_{pv} is lower than the ground by u_{dc}. In this situation, the u_{Cpv} is $-u_{dc}$. So, whether in the positive grid period or in the negative grid period, the voltage of the PV stray capacitance, u_{Cpv}, is kept constant. The common-mode current i_{cm} is mainly induced by the fluctuation of u_{cm} as expressed in (1)

$$i_{cm} = C_{pv} \frac{du_{cm}}{dt} \qquad (1)$$

So, the common mode leakage current can be limited to a low level in the proposed topology. The relevant common-mode waveforms are shown in Fig. 8 where the leakage current, i_{cm}, is lower than 0.05A. Thus, the common-mode characteristic of the proposed topology satisfies the standards, e.g. DIN VDE 0126-1-1.

IV. Simulation And Experimental Results

The simulation and experimental results are shown in this section. The proposed inverters in Fig. 4 were simulated in Matlab/Simulink. The DC voltage is 400V, and the grid voltage is 220V/50Hz. The switching frequency is 10kHz. The output inductor is 2mH. The grid current is controlled by a conventional PR controller. Fig. 9 shows the simulated switching signals of the proposed inverter. Fig. 10 shows the filtering current and switching current of the proposed inverter. The current waveforms of the switches are all unidirectional which indicate that no freewheeling current is flowing through the body diodes of the MOSFET. So the proposed inverter will not be threatened by the reverse recovery issue, thus the reliability of the inversion system is largely improved.

In order to further validate the proposed topology and the modulation strategies, the 1kW experimental prototype of the proposed inverter in Fig. 4 was built with the same parameters as the simulation model. The experimental results are shown in Fig. 11 and Fig. 12. Fig. 11 represents the experimental switching signals of the proposed inverter. Fig. 12 shows the grid current, the common mode leakage current and the output voltage of the proposed inverter from the top to the bottom of the picture respectively.

V. Conclusion

This paper reviews the already published dual buck topologies. The advantages and disadvantages of the dual buck inverters are specifically analyzed. In order to solve the main drawback of low magnetic utilization, a kind of phase leg topology is proposed. By applying the novel phase leg to the full bridge inverter, the new topology maintain the high reliability of the traditional dual buck inverter and the magnetic utilization is largely improved. Also, compared to the traditional single inductor dual buck inverter, the novel topology has the advantages in conducting loss and controlling complexity. The simulation and experimental results verified the performance of proposed inverter.

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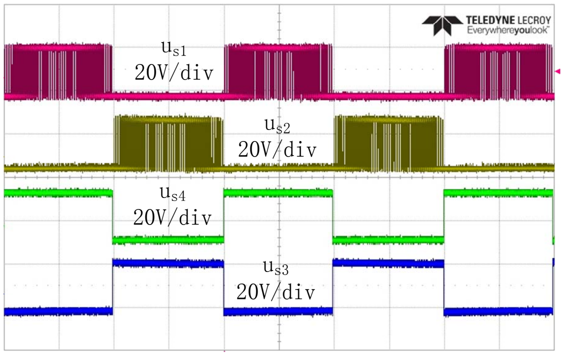

Fig. 11. The experimental driving voltage of the proposed inverter.

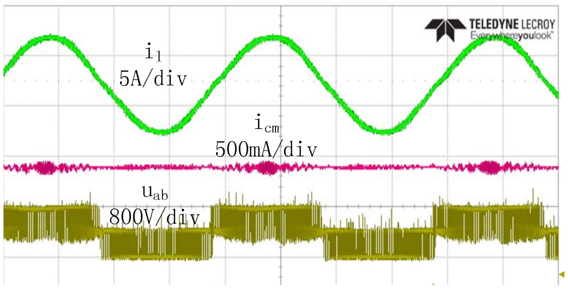

Fig. 12. The experimental output waveforms of the proposed inverter.

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