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Power Quality Improvement in Distribution System by Using Novel Isolated Multi Level Dc to Dc Power Converter

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ABSTRACT: This paper presents the implementation of a bidirectional dc-dc converter to protect a battery from overcharging and undercharging. The proposed converter circuit provides low voltage stresses across the switches, higher step-up and step-down voltage gains and efficiency is also high when compared to conventional boost/buck converter. The proposed control circuit controls the charging and discharging of the battery. The operating principle and steady state analysis for the step-up and step-down modes are discussed only in continuous conduction mode. Finally, 13/39-V prototype circuit is implemented to verify the performance of proposed converter

INTRODUCTION Bidirectional dc–dc converters are used to transfer the power between two dc sources in either direction. These converters are widely used in applications, such as hybrid electric vehicle energy systems, uninterrupted power supplies, fuel-cell hybrid power systems, photovoltaic hybrid power systems, and battery chargers. Many bidirectional dc–dc converters have been researched. The bidirectional dc–dc flyback converters are more attractive due to simple structure and easy control [2], [10]. However, these converters suffer from high voltage stresses on the power devices due to the leakage inductor energy of the transformer. In order to recycle the leakage inductor energy and to minimize the voltage stress on the power devices, some literatures present the energy regeneration techniques to clamp the voltage stress on the power devices and to recycle the leakage inductor energy [11], [12]. Some literatures research the isolated bidirectional dc–dc converters, which include the half bridge [5], [6] and full-bridge types [9].These converters can provide high step-up and step-down voltage gain by adjusting the turns ratio of the transformer. For non-isolated applications, the non-isolated bidirectional dc–dc converters, which include the conventional boost/buck [1], [4], [8], multilevel [3], three-level [7], sepic/zeta [16], switched capacitor [17], and coupled inductor types [18], are presented. The multilevel type is a magnetic-less converter, but 12 switches are used in this converter. If higher step-up and step-down voltage gains are required, more switches are needed. The total system is useful to avoid the damage to the life of the Batteries. Because of overcharging and undercharging batteries will produce hot spots inside the battery such that the batteries not survive for long time. The following sections will describe the operating principles and steady-state analysis for the step-up and step-down modes in continuous conduction mode only. In order to analyze the steady-state characteristics of the proposed converter, some conditions are assumed: The ON-state resistance $RD(ON)$ of the switches and the equivalent series resistances of the coupled inductor and capacitors are ignored; the capacitor is sufficiently large; and the voltages across the capacitor can be treated as constant.

CIRCUIT CONFIGURATION AND OPERATING PRINCIPLE

Figure 1 shows the proposed isolated multi-level DC-DC power converter. As can be seen in Fig.1,it is consisted of an isolated power converter, a series/parallel switching circuit and an output L-C filter. The isolated power converter is composed of a half-bridge inverter (C1, C2, S1, S2), a three-winding transformer (Tr1) and two full-bridge rectifiers (D1~D8, C3, C4).The duty cycle for the power electronic switches,S1and S2, of the half-bridge inverter is constant and

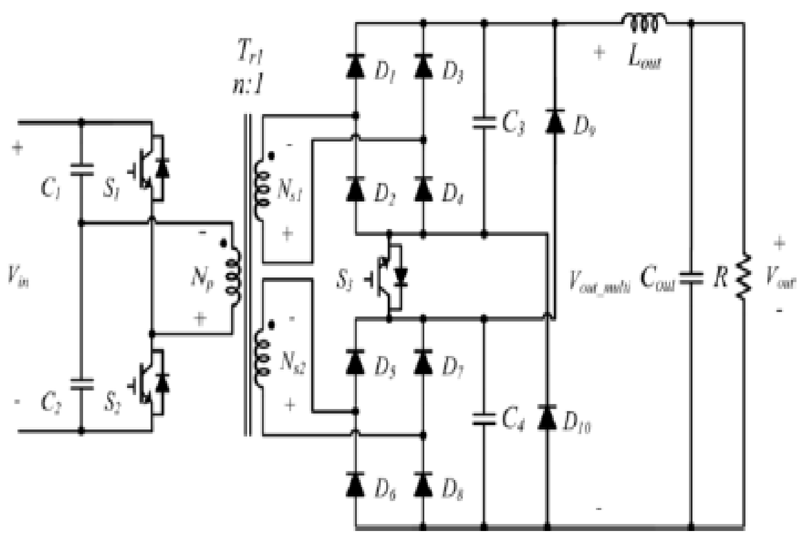

Fig. 1proposed isolated multi-level DC-DC power converter equal to 0.5.The isolated power converter is switched in constant duty to generate two output DC voltages through two secondary windings of the three-winding transformer and two full-bridge rectifiers. The number of windings, Ns1 and Ns2, are the same. Hence, the two output DC voltages of isolated power converter are almost the same. The series/parallel switching circuit contains a power electronic switch (S3) and two diodes (D9, D10). The series/parallel switching circuit is used to connect the two output DC voltages from the isolated power converter connected in series or in parallel by controlling S3. Therefore the voltage at the input of the output L-C filter is switched into two voltage levels.

The voltage at the input of the output L-C filter is equal to the output DC voltage of the isolated power converter when the two output DC voltages are connected in parallel and two times that of the output DC voltage of the isolated power converter when the two output DC voltages are connected in series. Therefore, the voltage variation is reduced to reduce the capacity of the output L-C filter. The amount of power electronics is less than that for isolated multi-level DC-DC converters that generate a multi-level ac voltage in the primary windings of the transformer [3, 14, 15]. In addition, only the power electronic of the series/parallel switching should be controlled, and the control circuit is also simplified.

The switching frequency for the power electronic switch, S3, is twice that for the power electronic switches, S1 and S2. The operation of the proposed isolated multi-level DC-DC power converter can be divided into four modes, depending on the switching operation of S1、S2 and S3. The equivalent circuits are shown in Fig.2.

Mode I

Figure 2(a) shows the equivalent circuit for mode I. In this mode, S1 is turned on and S2andS3 are turned off. Figure 2(a) shows that the two output DC voltages from the two rectifiers are connected in parallel. The turn ratio between the primary winding and the secondary windings is:

$$n = \frac{N_p}{N_{s1}} = \frac{N_p}{N_{s2}} \qquad (1)$$

Therefore, the voltage at the input of the output L-C filter can be written as:

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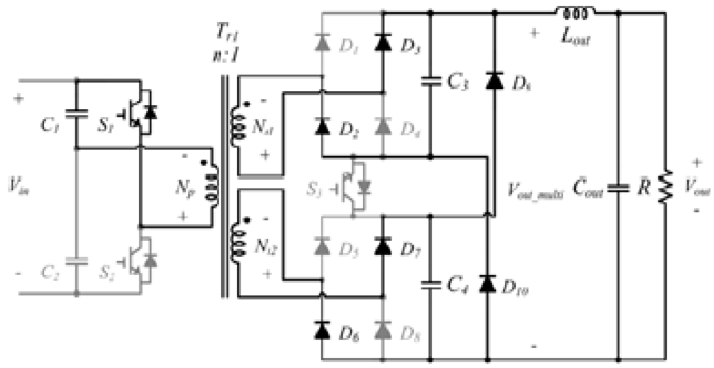
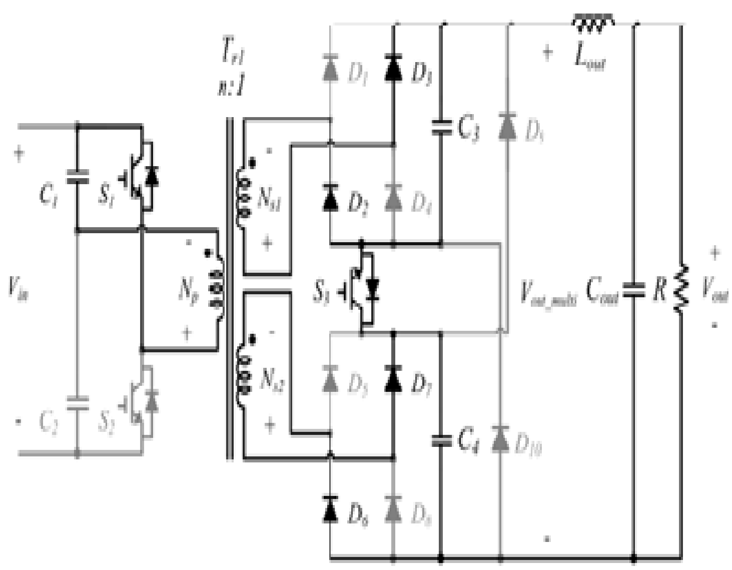
$$V_{out\_multi} = \frac{V_{in}}{2n} \qquad (2)$$

Mode II

Figure 2(b) shows the equivalent circuit for mode II. In this mode, S1 and S3 are turned on and S2 is turned off. As seen in Fig.2(b), the two output DC voltages from the two



(a)



(b)

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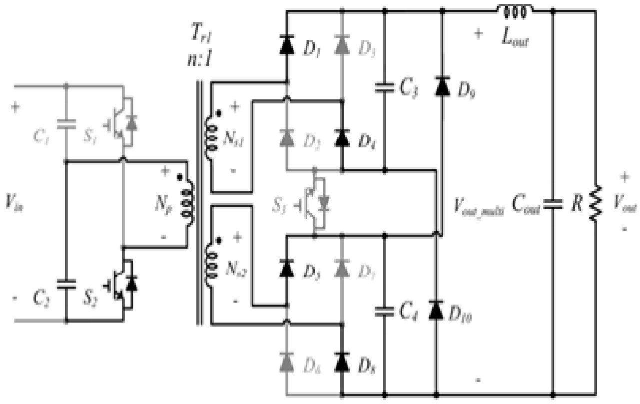
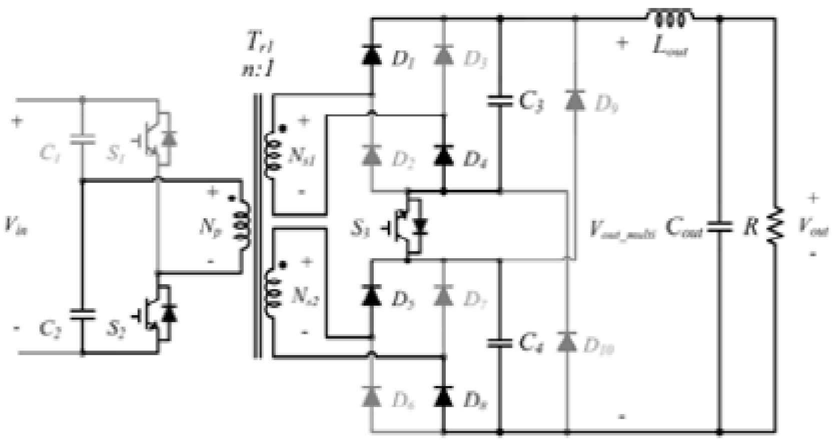


(c)



(d)

Fig.2 equivalent circuits of the proposed isolated multi-level DC-DC power converter, (a) mode I, (b) mode II, (c) mode III, (4) mode IV.

rectifiers are connected in series. The voltage at the input of the output L-C filter can be written as:

$$V_{out\_multi} = \frac{V_{in}}{n} \quad (3)$$

Mode III

Figure 2(c) shows the equivalent circuit for mode III. In this mode, S2 is turned on and S1 and S3 are turned off. It can be found in Fig.2(c) that the two output DC voltages from the two rectifiers are connected in parallel. The voltage at the input of the output L-C filter can be written as:

$$V_{out\_multi} = \frac{V_{in}}{2n} \quad (4)$$

Mode IV

Figure 2(d) shows the equivalent circuit for mode IV. In this mode, S2and S3 are turned on, and S1 is turned off. Figure 2(d) shows that the two output DC voltages from the two rectifiers are connected in series. The voltage at the input of the output L-C filter can be written as:

$$V_{out\_multi} = \frac{V_{in}}{n} \quad (5)$$

From this description, the relationships between the operating modes, the state of the power electronic switches and the voltage at the input of the output L-C filter for the

Table I

relationships of operation modes, S1, S2, S3andVout_multi

	S_1	S_2	S_3	V_{out_multi}
mode I	ON	OFF	OFF	$V_{in}/2n$
mode II	ON	OFF	ON	Vin/n
mode III	OFF	ON	OFF	$Vin/2n$
mode IV	OFF	ON	ON	Vin/n

proposed isolated multi-level DC-DC power converter can be summarized as shown in Table I. Since the two output DC voltages are connected in parallel and discharged during modes I and III, their voltages will be balanced automatically. In addition, the two output DC voltages are connected in series and discharged during modes II and IV such that their output currents are equal automatically. Hence, capacities of two secondary windings, Ns1 and Ns2 are almost equal.

The leakage inductance of transformer will result in the commutation of rectifiers. C3and C4 are applied to overcome the voltage variation induced by the commutation of rectifiers, and small capacity of film capacitors is used. As seen in Figs. 2(a) and (c), the voltage rating of S3 is equal to the output DC voltage (Vin/2n) from the rectifier. It can be found in Figs. 2(b) and (d) that the current of S3 is equal to the current of inductor Lout.

Figure 3 shows the time sequence for the proposed isolated multi-level DC-DC power converter. The switching frequencies of S1 and S2 are fs and the switching frequency of S3 is 2fs. The duty cycles of S1 and S2 are equal to 50%. The duty cycle of S3, shown in Fig.3(e), is used to control the output voltage to supply the load. The output voltage from the isolated multi-level DC-DC power converter is the average of voltage, Vout_multi, which can be derived as:

$$V_{out} = (1 + \mathrm{D})\frac{V_{in}}{2n} \qquad (6)$$

where D is the duty cycle of S3. As can be seen in Fig. 3, the voltage at the input of the output L-C filter is between Vin/n and Vin/2n. The current variation of inductor Lout under the continuous conduction mode (CCM) can be derived as:

$$\Delta I_{Lout} = \frac{\mathrm{D}(1-\mathrm{D})\mathrm{V_{out}}}{2(1+\mathrm{D})\mathrm{L}_{out}f_s} \qquad (7)$$

where Lout is the inductance of output L-C filter and fs is the switching frequency. For the conventional isolated power converter, the voltage at the input of the output L-C filter is between 0 and Vin/n, and the current variation of filter inductor under CCM can be derived as:

$$\Delta I_c = \frac{(1-\mathrm{D_c})\mathrm{V_{out}}}{2\mathrm{L_f f_s}} \qquad (8)$$

where Lf is the inductance of output L-C filter, and Dc is the duty cycle of half-bridge inverter for the conventional isolated DC-DC power converter. It should be noted that D for the proposed isolated multi-level DC-DC power converter is not equal to Dc for the conventional isolated power converter. In the condition of the same input and output voltages, the relation between D and Dc can be derived as:

$$\mathrm{D}_c = (1 + \mathrm{D})/2 \qquad (9)$$

If the output voltage is constant and Lout is equal to Lf, the relation for the current variations, $\Delta ILout$ and ΔIc, under the same input voltage can be represented as:

$$\frac{\Delta I_{Lout}}{\Delta I_c} = \frac{2D}{(1+D)} \quad (10)$$

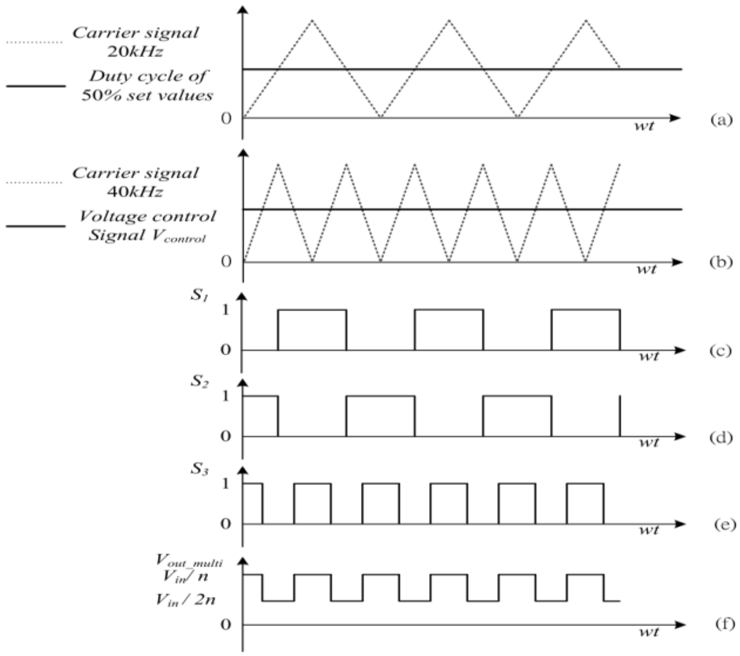


Fig. 3 time sequence of the proposed isolated multi-level DC-DC power converter, (a) carrier and control signals of S1and S2, (b) carrier and control signals of S3, (c) driver signal of S1, (d) driver signal of S2, (e) driver signal of S3, (f) waveform of Vout multilevel.

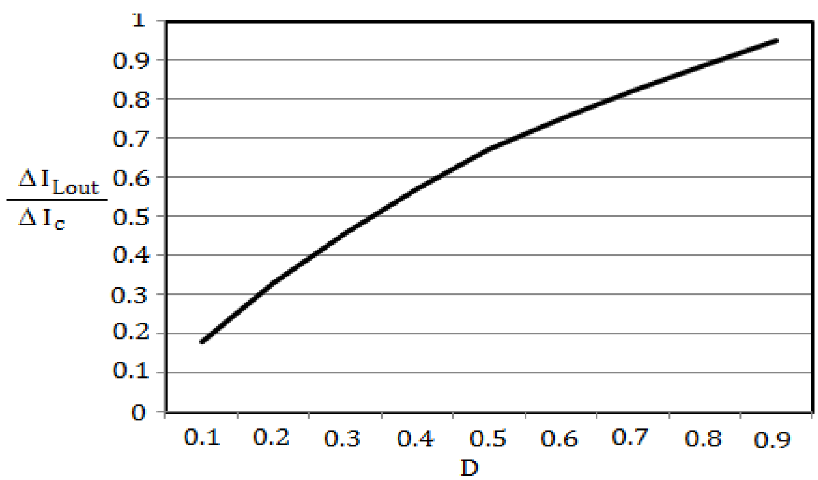


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Figure 4 shows the curve of □ILout/□Ic. As can be seen, □ILout/□Ic is proportion to D. It can be found that the current variation of filter inductor for the proposed isolated multi-level DC-DC power converter is smaller than that for the conventional isolated power converter under the same output L-C filter. As compared with the conventional isolated power converter, the proposed isolated multi-level DC-DC power converter increases the complexity of power circuit but reduces the inductance of the output L-C filter under the same current variation. The reducing amount of inductance of the output L-C filter for the proposed isolated multi-level DC-DC power converter is dependent on D.

EXPERIMENTAL RESULTS

To verify the performance of the proposed isolated multi-level DC-DC power converter, a prototype was produced and tested. Table II shows the major parameters for the hardware of the prototype. Figure 6 shows the experimental results for the gate signals of the power electronic devices, S 1, S 2 and S 3. It is seen that the gate signals for the power electronic devices, S 1 and S 2 , are out of phase, and the frequency of the gate signal for S 3 is twice that of the gate signal for S 1 and S 2. Figures 7 and 8 show the experimental results for the proposed multi-level DC-DC converter. Figures 7(a) and 7(b) show the voltage across the transformer's primary winding and secondary winding. Figures 7(c) and 7(d) show the voltage, V out_multi, and the current in the filter inductor. It is seen that the voltage, V out_multi, switches between two levels (215V and 430V). Compared with a conventional isolated DC-DC power converter wherein the voltage is switched between two levels (0 and 430V), the switching harmonic for the proposed multi-level DC-DC converter is reduced so the capacity of output L-C filter can be reduced. Figure 8 shows the voltages and currents for the input side and the output side for the isolated multi-level DC-DC power converter. As seen in Figs. 8(a) and 8(b), the input voltage is 400V and the input current is 5.09A. Figures 8(c) and 8(d) show that the output voltage is 380V and the filter inductor current is

Table II major parameters of the prototype

V_{in}	$400V$
V_{out}	$380V$
P_{out}	$2kW$
switching frequency of $S_1$and S_2	$20kHz$
switching frequency of S_3	$40kHz$
C_1andC_2	$2200\mu F$
C_3 andC_4	$20\mu F$
N_p:N_{s1}:N_{s2}	24:26:26
magnetizing inductance of transformer	$4.5mH$
leakage inductance of transformer	$0.5\mu H$
L_{out}	$88\mu H$
C_{out}	$2200\mu F$

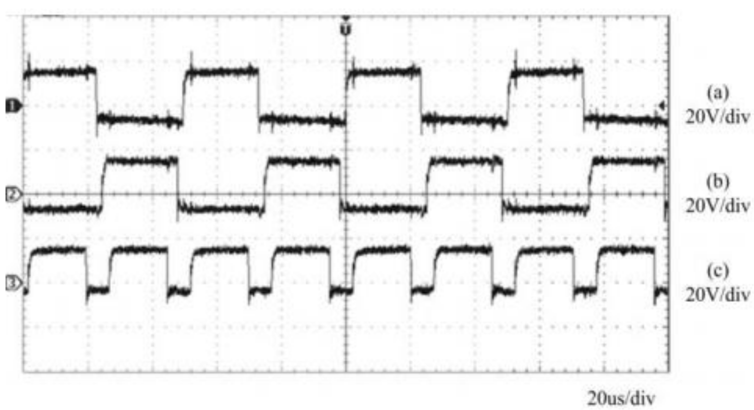

Fig. 6 experimental results for the gate signals of power electronic devices, (a) gate signal of S1, (b) gate signal of S2, (c) gate signal of S3

CONCLUSION In this paper, a novel bidirectional dc–dc converter with battery protection is proposed. The circuit configuration of the proposed converter is very simple. The operation principle, including the operation modes and steady-state analysis is explained in detail. The proposed converter has higher step-up and step-down voltage gains and lower average value of the switch current than the conventional bidirectional boost/buck converter. From the experimental results, it is see that the experimental waveforms agree with the operating principle and steady-state analysis.

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