A Novel Isolated Buck-Boost Converter

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Abstract — This paper proposed a novel Isolated Buck-Boost PWM DC-DC converter circuit. The topology which merged buck-boost mode with flyback mode can share the transformer and switch. Not only isolated buck-boost mode current but also flyback mode current added on the one output current of the converter because the topology merged buck-boost mode with flyback mode. A new converter has outstanding advantages over the conventional dc-dc converters with respect to high efficiency, high power density, and component utilization. The operation principle of the proposed converter is described and verified by simulation and experiment results. Also this paper presents novel circuit and simulation result of new active isolated buck-boost converter.

I. Introduction

Recently, a Switched-Mode Power Supply is widely used as a power equipment to supply a stable DC power to an electronic circuit part of all of electronics and communication equipments such as portable telecom devices, telecommunication power system, power conditioning system for renewable energy etc. There are two types of the isolated converter of which main switch uses only a single one: one is a forward type which transfers power when a switch is turned on, and the other is a flyback type which transfers power when a switch is turned off. The isolated DC-DC converter is more efficient than non-isolated converter because of most applications require the isolation between the input and the output. Therefore, if possible, it is desirable to make the DC-DC converter in the form of an isolated type.

However, the efficiency of isolated DC-DC converters is limited because isolated DC-DC converters can transfer energy of a primary circuit to a secondary circuit only when a switch is turned on or off.

Accordingly, this paper present a new type of isolated buck-boost converter which can increase the efficiency of the converter.

II. Isolated Buck-Boost Converter

Fig. 1 shows new isolated buck-boost converter (hereafter called "IBB" converter). IBB converter according to a Fig. 1 in which an input circuit is isolated from an output circuit by a transformer T, wherein the input circuit comprises a DC source, a primary coil of the transformer T connected in series to the DC source, and a switch Q which is connected in series to the primary coil of the transformer T and which performs on/off switching; and wherein the output circuit comprises a secondary coil of the transformer T corresponding to the primary coil of the transformer T, an inductor L connected in parallel to the secondary coil of the transformer T, a diode D of which cathode is connected to one node between the secondary coil of the transformer T and the inductor L, a capacitor C connected to the other node between the secondary coil of the transformer T and an anode of the diode D, and a load resistor R connected in parallel to the capacitor C. Proposed converter performs as a buck-boost converter. It can either increase or decrease the magnitude of the dc voltage of the converter. Merging buck-boost converter with flyback topology can share the transformer and power MOSFET. Not only isolated buck-boost mode current but also flyback mode current added on the one output current of the converter. A new converter has outstanding advantages over the conventional dc-dc converters with respect to high efficiency, high power density, and component utilization.
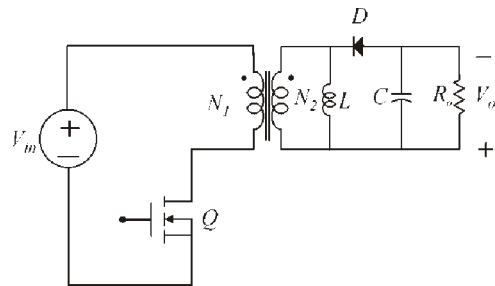

Fig. 1. A Novel IBB Converter.

A. Behavior of novel IBB converter

The proposed IBB converter is analyzed. There are two topological states in one switching cycle. The equivalent circuits for these states are shown in Fig. 2. Now we explain the operation of the circuit shown in Fig.1.

For this description of circuit operation, the following assumptions are made.

- Ideal switching components.
- Steady-state CCM operation.

Stage ١: If the switch (Q) is turned on (t.-t١), the input voltage (V$_{in}$) is supplied to the primary portion of the transformer and the input energy is then stored in the inductor (L). Now, the diode (D) is reverse-biased and thus is turned off. Therefore, the buck-boost converter circuit is operated as shown in Fig. ٢.
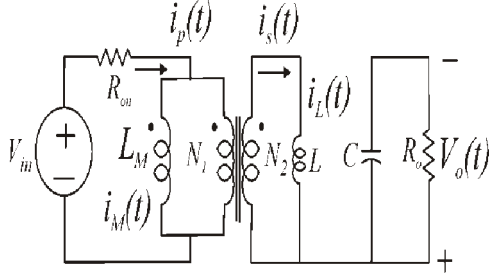

Fig. ٢. Stage ١(at t.-t١).

In this case, let a voltage of DC source (S) be V$_{in}$, a switch turn-on resistor be R$_{on}$, a transformer magnetizing inductance be L$_M$, a magnetizing current be I$_M$, the inductance of an inductor be L, an inductor current be I$_L$, the output voltage be Vo, and a ratio of turns of the primary coil to the secondary coil be N(=N$_٢$/N$_١$), the circuit equation are as follows:

$$k_١\dot{X} = A_١X + B_١U(t)$$
$$Y = C_١X + D_١U(t) \tag{١}$$
$$(t_. \le t \le t_١)$$

Where $X(t) = [i_M(t) \quad i_L(t) \quad V_o(t)]$

$$K_١ = \begin{bmatrix} L_M & \cdot & \cdot \\ \cdot & L & \cdot \\ \cdot & \cdot & \cdot \end{bmatrix} z$$

$$A_١ = \begin{bmatrix} -R_{on} & \cdot & \cdot \\ \cdot & -N^٢R_{on} & \cdot \\ \cdot & \cdot & -\frac{١}{R} \end{bmatrix}$$

$$B_١ = \begin{bmatrix} ١ & \cdot \\ N & \cdot \\ \cdot & \cdot \end{bmatrix}$$

$$C_١ = \begin{bmatrix} ١ & \cdot & \cdot \\ \cdot & N & \cdot \\ \cdot & \cdot & \cdot \end{bmatrix}$$

$$D_١ = \begin{bmatrix} \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \end{bmatrix}$$

Stage ٢: Also, when the switch (Q) is turned off (t١-t٢), the diode (D) is forward-biased and then is turned on. Therefore, the isolated buck-boost circuit is operated as shown in Fig. ٣. In such a circuit, the energy stored in the inductor (L) is discharged to a load resistor, and also the energy stored in the magnetizing inductor (L$_M$) is discharged via the secondary coil of the transformer. And, the inductor current (I$_L$) and the current (I$_{S٢}$) on the secondary coil of the transformer are added to a diode current. Consequently, the following equation is established:
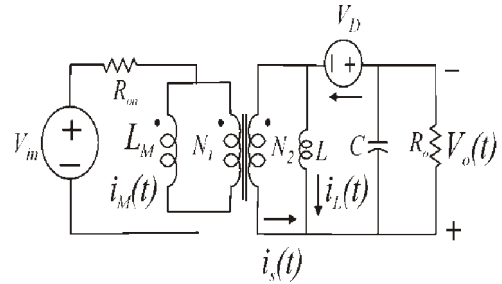

Fig. ٣. Stage ٢(at t١-t٢).

$$k_٢\dot{X} = A_٢X + B_٢U(t)$$
$$Y = C_٢X + B_٢U(t) \tag{٢}$$
$$(t_١ \le t \le t_٢)$$

Where $X(t) = [i_M(t) \quad i_L(t) \quad V_o(t)]$

$$K_٢ = \begin{bmatrix} L_M & \cdot & \cdot \\ \cdot & L & \cdot \\ \cdot & \cdot & \cdot \end{bmatrix}$$

$$A_٢ = \begin{bmatrix} \cdot & \cdot & \frac{١}{N} \\ \cdot & \cdot & ١ \\ \frac{١}{N} & -١ & -\frac{١}{R} \end{bmatrix}$$

$$B_٢ = \begin{bmatrix} \cdot & -\frac{١}{N} \\ \cdot & -١ \\ \cdot & \cdot \end{bmatrix}$$

$$C_٢ = \begin{bmatrix} \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \end{bmatrix}$$

$$D_{\Upsilon} = \begin{bmatrix} \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \end{bmatrix}$$

In the steady state, a DC analysis by the duty ratio D is as follows:

$$X = -A^{-1}BU$$
$$Y = (-CA^{-1}B + D)U \qquad (\Upsilon)$$

$$A = \begin{bmatrix} -DR_{on} & \cdot & (\backslash - D)\big/N \\ \cdot & -DN^{\Upsilon}R_{on} & (\backslash - D) \\ (\backslash - D)\big/N & -(\backslash - D) & -\backslash\big/R \end{bmatrix}$$

$$B = \begin{bmatrix} D & -(\backslash - D)\big/N \\ ND & -(\backslash - D) \\ \cdot & \cdot \end{bmatrix}$$

$$C = \begin{bmatrix} D & \cdot & \cdot \\ \cdot & ND & \cdot \\ \cdot & \cdot & \cdot \end{bmatrix}$$

$$D = \begin{bmatrix} \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \end{bmatrix}$$

If $\quad R_{on} = \cdot, \quad V_D = \cdot$

$$\cdot = \frac{(\backslash - D)}{N}V_o + DV_{in} \qquad (\Upsilon)$$

$$\cdot = -(\backslash - D)(\frac{\backslash}{N}I_M + I_L + \frac{\backslash}{R}V) \qquad (\vartriangle)$$

From equation $(\Upsilon),(\vartriangle)$

$$V_o = -N\frac{D}{\backslash - D}V_{in} \qquad (\varphi)$$

$$\frac{\backslash}{N}I_M + I_L = -\frac{\backslash}{R}V_o \qquad (\vee)$$

$$I_o = -\frac{\backslash}{R}V_o \qquad (\wedge)$$

Where $I_o = \frac{\backslash}{N}I_M + I_L$

$$V_o = \frac{N_{\Upsilon}}{N_{\backslash}}\frac{D}{\backslash - D}V_{in} \qquad (\vartheta)$$

So the conversion ratio of the proposed converter is similar to the buck-boost converter, but contains an added factor of N. Where $N = \frac{N_{\Upsilon}}{N_{\backslash}}$

And also, the output current I_o consists of the inductance current I_L and the transformer magnetizing current I_M. It can be understood that when $N_{\backslash}=N_{\Upsilon}$, the output of the isolated buck-boost converter increases in power and the current of the buck-boost mode and the current of the flyback mode are combined into one output current of the converter.

Fig. φ shows the time sequence of gate drive voltages for switch Q, the main switch voltage V_{DS}, the main switch current $I_{s\backslash}$, the current through transformer coil of secondary side $I_{s\Upsilon}$, the diode current I_D, and the inductor current I_L.
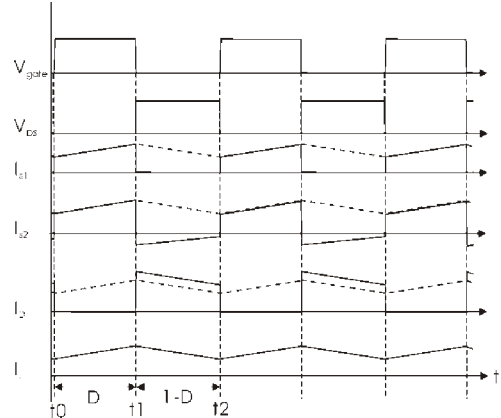

Fig. φ. Key Waveform of the IBB converter.

B. A Novel Active Clamp IBB Converter

Fig. $\vartriangle$ shows new active clamp IBB converter.

And Fig. φ shows the key waveform of the active clamp IBB converter. The auxiliary switch Q_{Υ} is used to provide a path for recycling the magnetizing energy.

The new converter's features are as the following advantages.

Both the main and auxiliary switches operate with zero voltage switching.

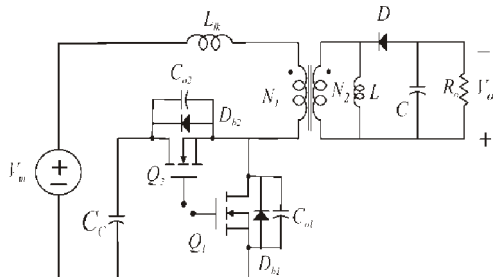Soft switching can be maintained for full line range and load range.

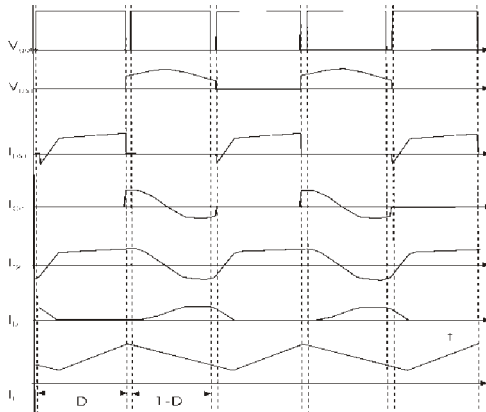Fig. ٥. Novel Active Clamp IBB Converter.

Fig. ٦. Key Waveforms of the Active Clamp IBB Converter.

III. SIMULATION AND EXPERIMENT RESULT

We did the simulations using the Fig. ١ circuit and Fig. ٥ circuit for proposed converter. The simulation was done with ٥٠٪ duty ratio.

The simulation and experiment results of the IBB converter are presented in Fig. ٧, Fig. ٨ and Fig. ٩.
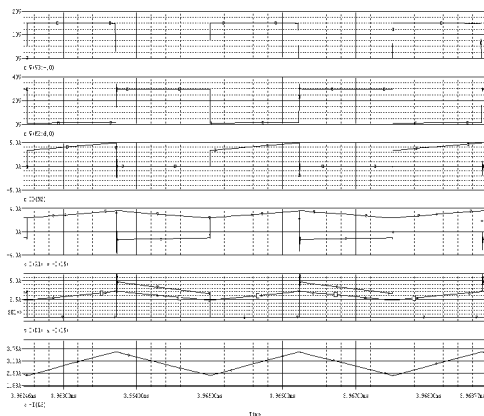

Fig. ٧. Simulation Waveforms of the IBB Converter.

Fig. ٧ shows the gate drive voltages for switch Q, the main switch voltage V_{DS}, the main switch current $I_{s١}$, the current

through transformer coil of secondary side $I_{s٢}$, the diode current I_D, and the inductor current I_L.
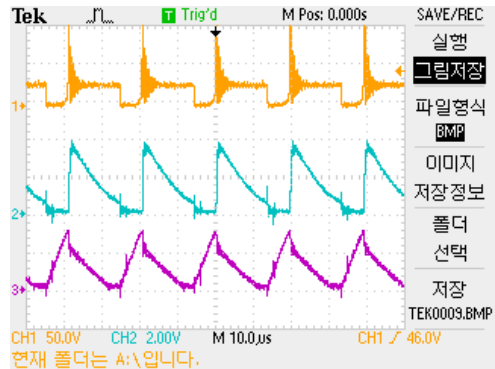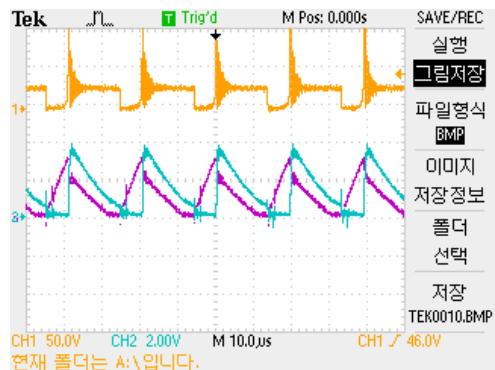

Fig. ٨. Experiment Waveforms of the IBB Converter.

Fig. ٩. Experiment Waveforms of the IBB Converter.

Fig. ٨, Fig. ٩ shows the main switch voltage V_{DS}, the diode current I_D, and the inductor current I_L.

The simulation and experiment results agree well with the theoretical waveforms.

And also we could identify that the IBB converter's output current I_o consists of the inductance current I_L and the transformer magnetizing current I_M through the experiment waveform of the diode current I_D, and the inductor current I_L.

From the simulation and experiment results, the proposed converter could transfer energy of a primary circuit to a secondary circuit when a switch is on and off because isolated DC-DC converters which main switch uses only a single one can transfer energy of a primary circuit to a secondary circuit only when a switch is turned on or off.

And we also do the simulation for a new active clamp IBB converter. The simulation and experiment results of the active clamp IBB converter are presented in Fig. ١٠.
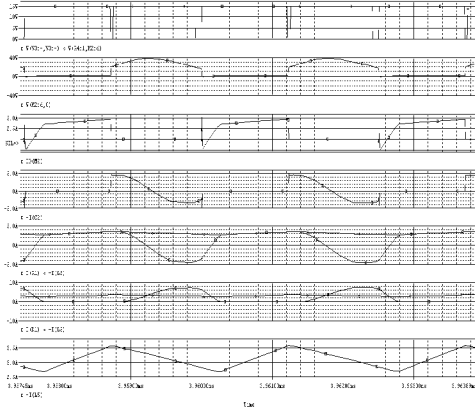
Fig. ۱۰. Simulation Waveforms of Active Clamp IBB Converter.

Fig. ۱۰ shows the gate drive voltages for the switch Q_1 and clamp switch Q_2, the main switch voltage V_{DS1} , the main switch current I_{DS1}, the clamp capacitor current I_{Cc}, the current through the coil of transformer's secondary side I_{T2}, the diode current I_D, and the inductor current I_L.

The simulation results agree well with the theoretical waveforms.

IV. CONCLUSION

A new IBB converter topology has been presented. The topology which merged buck-boost mode with flyback mode can share the transformer and switch. Not only buck-boost mode current but also flyback mode current added on the one output current of the converter because the topology merged buck-boost mode with flyback mode. A new converter has outstanding advantages over the conventional dc-dc converters with respect to high efficiency, high power density, and component utilization. The operation principle of the proposed converter is described and verified by simulation and experiment results. Also this paper presents novel circuit and simulation result of new active isolated buck-boost converter. The incorporation of the active clamp circuit into the proposed converter topology provides a mechanism for achieving ZVS for both the main and auxiliary switches.

REFERENCES

[۱]   Robert W. Erickson, Dragan Maksimovic, *Fundamental of Power Electronics*, International Thomson publishing.
[۲]   R. Watson, G. C. Hua, F. C. Lee, "Characterization of an active clamp flyback topology for power factor correction applications", *Proceedings of the Ninth Annual Applied Power Electronics Conference*, PP ۴۱۲-۴۱۸،۱۹۹۴.
[۳]   R. Watson, G. C. Hua, F. C. Lee, "Characterization of an active clamp flyback topology for power factor correction applications", *Proceedings of the Ninth Annual Applied Power Electronics Conference*, PP ۴۱۲-۴۱۸،۱۹۹۴.
[۴]   R. Watson, G. C. Hua, F. C. Lee, "Characterization of an active clamp flyback topology for power factor correction applications", *Proceedings of the Ninth Annual Applied Power Electronics Conference*, PP ۴۱۲-۴۱۸،۱۹۹۴.