DESIGN AND ANALYSIS OF ZCS CURRENT-FED FULL-BRIDGE CONVERTER

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ABSTRACT
A new soft-switched, current-driven full-bridge converter is presented. The new topology has the advantages of simple circuit topology, soft switching implementation with simple snubber device, high efficiency and simple control and is formed by two unidirectional switches and a capacitor to realize soft switching operation over a wide line and load range. The energy used for soft-switching is self-adaptable. For a given input current, the snubber capacitor is charged to the minimum required energy for ZCS of the switches. Thus, less resonant energy is used and the conduction loss can be kept minimal. The cyclical switching operation and control of the converter will be simulated using MATLAB 7.5b. This proposed method make the converter promising for medium and high power applications are required. The experimental results measured on a 5-kw, 530-5300kv confirms the advantages of the proposed converter.

KEY WORDS
Adaptable soft-switching, dc-dc conversion, high voltage converter, zero-current switching (ZCS), pulse-width modulation.

I. INTRODUCTION

Power electronic devices contribute with an important part of all kind of applications, such as power rectifiers, converters. In electronics engineering, a DC to DC converter is a circuit which converts a source of direct current from one voltage to another. Nowadays full-bridge (FB) converter is predominantly the front-end power processor in typical power supply systems. It constitutes a part of power factor correction (PFC) in a Single - stage ac–dc conversion. Or, it is the stage that follows the boost-type PFC for converting universal ac line into dc bus in a two-stage system.

In order to operate the pulse width modulated (PWM) FB converters at high switching frequency and efficiency, various soft-switching techniques have been proposed. However, a zero-current switching (ZCS) condition is achieved to switch the lagging switches on and off by resetting the primary current during the freewheeling stage. The first consequence is the avoidance of the circulation of the primary current during the freewheeling stage. To bring and keep the primary current to zero before finishing the turn ON/turn-OFF process, a number of passive and active solutions have been proposed, at the expense of either higher circuit complexity and/or overvoltage across the rectifier. For all ZVS and ZVZCS solutions, the most interesting strategy is the one that can ensure soft switching at light load. The snubber energy is load-adaptable, i.e., more resonant energy is available only when needed at light load.

In high-voltage applications, each switch could theoretically be realized by connecting two transistors in series. However, the equipment cost has to include that of the eight switches in the FB structure. Three-level solutions have been proposed for clamping the voltage on the primary switches to half of the input voltage. This paper proposes a new snubber that is inserted in the primary side of a current-driven FB converter. ZCS of the power switches is obtained at a very wide line and load range, starting from a low value of the input current, by always using the minimum necessary energy. The snubber switches are operated with ZVS.

II. CONVENTIONAL METHOD

In ZVS converters, one uses MOSFETs as primary-side switches. One of the disadvantages of the ZVS operation is the primary current circulation during the freewheeling stage, which leads to unnecessary conduction losses. This problem is solved in ZVZCS converters, where, by bringing the primary current to zero during the freewheeling stage, the lagging-leg switches turn-on/off with ZCS. Consequently, the lagging-leg switches can be implemented with IGBT transistors, which can withstand a higher voltage. However, as the leading leg's switches turn-on/off with ZVS, they have to be MOSFETs, in order to use their parasitic parallel capacitance. This limits the use of the ZVZCS converters. In high-voltage applications, each switch could theoretically be realized by connecting two transistors in series. However, the equipment cost has to include that of the eight switches in the FB structure. This approach does not work well as far as dynamic balancing is concerned, since no transistors are identical. Three-level solutions have been
proposed for clamping the voltage on the primary switches to half of the input voltage. These solutions not only imply a larger component count, but are also unsuitable for input voltages at several kilovolts, where the availability of MOSFET, if any, would make the system operate at a low switching frequency. To overcome these we are going for Voltage-driven FB ZCS converters.

**PROPOSED ZCS FB CONVERTER WITH ADAPTIVE SOFT-SWITCHING ENERGY**

The proposed current-driven FB converter is shown in Fig. 1. $L$ is the input inductor, $N_p$ and $N_s$ are the number of turns of the primary and secondary sides of Transformer, respectively, and $L_{lk}$ is its leakage inductance.

The snubber is formed by two unidirectional transistors $S_{a1}$ and $S_{a2}$ and one capacitor $C_r$. The switching diagram and switching topologies are given. $V_o$ is the output voltage, $i_p(t)$ is the primary current, $i_o$ is the secondary current, and $v_{Cr}$ is the voltage across $C_r$. Recent industrial applications, like medical X-ray imaging equipment, traveling wave tubes, RF generation, etc. require a very high-voltage supply system. In the dc–dc converters used for such applications, one has to use insulated-gate bipolar transistors (IGBTs), or other minority carrier devices for all the primary switches, as they can withstand high voltage. The best soft-switching technique for these devices with tail current at turn-OFF is ZCS. ZCS is also suitable for current-driven boost type output FB converters. However, there has been little research in FB ZCS converters. ZCS is achieved in current-driven converters, by using a passive snubber or an active one.
The input voltage range and load variation that assure both output voltage regulation and soft switching are graphically presented. The self-adjustability of the energy accumulated in the snubber for ZCS is explained.

IV. SWITCHING OPERATION

There are six modes of operation involved: they are,

**MODE 1** \([t_0, t_1]\):

Before \(t_0\), the circuit topology is shown in Fig. 3(a). The input energy is transferred to the load via diodes \(D_2\) and \(D_3\). At \(t_0\) a new cycle begins with \(S_1\) turning off with ZVS. \(C_r\) is being charged. ZCS can be achieved at high input current without unnecessarily increasing the capacitor’s accumulated energy at a lower input current.

**MODE 2** \([t_1, t_2]\):

During this mode at \(t_1\), \(i_p\) reaches zero, and \(S_3\) switched off with ZCS. As a result, the secondary current reaches zero, and the rectifier diodes turn-off naturally (ZCS).

**MODE 3** \([t_2, t_3]\):

During this stage At \(t_2\), \(i_p\) reaches zero, and \(S_5\) switched off with ZCS. As a result, the secondary current reaches zero, and the rectifier diodes turn-off naturally (ZCS).
MODE 4 \([t_3, t_4]\)

During this stage, The PWM will dictate the instant \(t_3\) when \(S_2\) is turned on with ZCS. The \(Cr\) energy is transferred to the load. The \(i_p\) goes negative and increases in absolute value \(D_1\) and \(D_4\) are turned on with ZCS. The stage ends when the primary current in absolute value reaches the input current.

MODE 5 \([t_4, t_5]\)

During this stage, At \(t_4\), \(i_p\) reached—\(fin\), and the current through \(S1\) dropped to zero, so \(S1\) can be turned off with ZCS. The energy is transferred from the line to the load. \(Cr\) is discharged to the load. This mode ends when \(Cτ\) is completely discharged.

MODE 6 \([t_5, t_6]\)

During this stage, at \(t_5\), \(S_{a2}\) turns on with ZVS, and the circuit operates in this transfer-energy mode until a new half-cycle is commenced by turning off \(S_{a2}\). \(S_1\) is turned on with ZCS at \(t_5\), and \(S_3\) is turned on and off with both ZCS and ZVS at \(t_1\) and \(t_8\), respectively. Operations of \(S_2\) and \(S_4\) are the same as \(S_1\) and \(S_3\), respectively. Thus, \(S_1–S_4\) are all switched with ZCS.

V. SIMULATION RESULTS

DESIGN PROCEDURE

The proposed converter is designed and implemented with \(V_{in}= 530 \pm 20\%\), \(P_{o,\text{rated}} = 5kW\), and \(V_o = 15 \text{ kV}\). A switching frequency of 20 kHz was used, giving \(Ts/2 = 25\mu s\).

1) The minimum boundary on \(Llk\) is chosen for achieving a soft increase in the primary current (i.e., of the current through \(S2\)) at \(t3\) when \(S2\) is turned on. By using one can choose the values of \(Cr\) and \(Llk\) for keeping the total duration of the resonant-purposed soft-switching intervals at \(4\mu s\).

2) The ratings of the switches are chosen by considering the voltage and current stresses. The voltage stress of the main switches is \(I_{in,\text{max}}\), and that of the auxiliary switches is \(I_{in,\text{max}}\). The current stress of all switches is \(I_{in,\text{max}}\).

3) The value of the input inductor is chosen to limit the input current ripple \(\Delta iL\) at 2.5% from its nominal value

\[
L \geq \frac{nD(1 - 2D)TsVo}{\Delta iL}
\]

4) The value of the output capacitor \(Co\) is chosen to limit the voltage ripple \(\Delta Vo\) at 0.6% of \(Vo\)

\[
Co > \frac{2D_{\text{max}}IoTs}{\Delta V}
\]

5) The output diodes are chosen by considering the voltage and current stresses. The voltage stress and current stress of the diode are \(Vo\) and \(Po,\text{max}/Vo\), respectively.

The four main switches are driven by phase-shift PWM signals with adaptable durations of charging and discharging intervals of the snubber capacitor. The driven signals of the two auxiliary switches are generated by detecting the zero cross point of the voltage of the snubber capacitor.
Figure 5. DC input voltage

Figure 6. Pulse and current through switch waveform.
Fig. 7 Trigerring pulse waveform

Figure 9. Inverter ac output
The experimental steady-state voltage and current waveforms of the primary switches \( S_1 \) and \( S_3 \), and auxiliary switch \( S_a \) under full-load, and at 25% load conditions, are given.

**VI. CONCLUSION**

A new soft-switched full-bridge converter utilizing a very simple snubber circuit has been proposed. It is particularly useful for high-voltage applications. The primary-side switches are operated with ZCS, allowing the use of IGBT. The auxiliary switches are operated with ZVS. The rectifier diodes are operated with ZCS naturally. The snubber capacitor can avoid unnecessary energy circulation, and thus reduce conduction loss. In each cycle, all the energy accumulated in the snubber capacitor for soft switching is recycled to the load.

Experimental results have been simulated using MATLAB 7.5b on a 530-V/5.3-Kv confirms the advantages of the proposed converter structure.

**VII. REFERENCES**


