A Soft Switching Technique Implemented in DC-AC Converter using Cycloconverter for UPS Application

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Abstract-   **A novel voltage source full-bridge DC-AC converter with pulse width modulation technique using a step down Cycloconverter is implemented. The zero-voltage switching (ZVS) commutation for full-bridge high frequency inverter active power switches and the Cycloconverter bi-directional switches are obtained. Soft switching operation is provided in a wide range of voltage regulation without utilizing an auxiliary inductor in the primary side of an isolating transformer. The transformer size and filter components value is reduced by using high frequency inverter. Therefore switching losses in the circuit can be reduced and output voltage is regulated. Based on the simulation and experimental results, the steady-state operation principles of the converter are analyzed.**

Keywords – Full bridge inverter, Cycloconverter with bi-directional switches, Zero voltage switching.

I. INTRODUCTION

Recently, medium power high-frequency converters have been widely used in several applications such as automobile and aircraft converters, switching power supplies, uninterruptible power supplies and speed controllers of electrical machines. Also inductive loads can be supplied by these types of converters, but in these cases they need to have bi-directional power flow. To minimize the size of the isolating transformer (IT) and output filter components, high frequency switching techniques are used, even if additional switching stresses and electromagnetic interference (EMI) noises are imposed to the circuit. Accordingly, overcoming these problems, several types of converters with zero-crossing modes were proposed. In [1-5] a full-bridge zero-voltage switching (ZVS) pulse width modulation (PWM) converter, which is used widely in high-power applications, is proposed in this paper. The ZVS operation principle is achieved by means of leakage inductance of the IT. In this converter the leakage inductance is too small. Therefore the stored energy is not sufficient to complete ZVS operation of full-bridge switches, even if high current flows through the primary windings.

In [2-4] several methods for extending the ZVS operation of full-bridge switches are proposed. Some of these suggested methods are based on either increasing the leakage inductance of the IT or adding an external inductance. Thus, the energy stored in the primary side of the IT is increased, and then the performance of switches under the ZVS condition can be improved. Even though the soft switching performance is improved by these methods, the primary-winding current is increased to high quantities. Consequently, the stored energy in the external inductance increases and eventually it provides high circulating currents in the switches. On the other hand, it increases the dead band time of the secondary-winding voltage.

The [7-8] Saturable type external inductor is used to obtain ZVS operation of full-bridge switches. So, the stored energy is limited when the primary-winding current reaches a high quantity. However, considerable losses on the auxiliary inductor are provided especially at high-frequency switching operation. Another inconvenience of these structures is the severe parasitic oscillations at the secondary side of the IT. These parasitic oscillations happen while the junction capacitance of diodes resonance with the external inductance or with the leakage inductance of the primary side of the IT. Another well-known solution to decrease switching losses is a passive snubber method. A novel Pulse width modulation (PWM) DC-AC converter, achieved almost full-range zero-voltage switching (ZVS) performance in the switches of a full-bridge converter by means of a Cycloconverter, without auxiliary inductor, presented in this paper.

The diodes of rectifier in the conventional topologies are superseded by the Cycloconverter bi-directional switches, operating under ZVS conditions. Additionally, the controller contains a high-frequency PWM technique and a reference signal detector to provide not only effective voltage regulation and ZVS commutation for the proposed topologies but also different output waveforms, which represent this structure as a multi-function converter. Because, the Cycloconverter Bi-directional and full-bridge switches operate under soft commutation conditions, switching stresses and losses are reduced.

II. OPERATION AND ANALYSIS OF THE PROPOSED CONVERTER

A. Converter topology –

The power circuit of the proposed ZVS converter that employs two bi-directional switches at the secondary side of isolating high-frequency transformer as a Cycloconverter is illustrated in Fig. 1. These bidirectional switches are controlled to achieve full range of ZVS performance on the full-bridge converter switches. The structure of the Cycloconverter is particularly simple and robust. Output voltage regulation is provided by phase shifting of leading-leg switches Q 3 and Q 4 with respect to lagging-leg switches Q 1 and Q 2. It should be noted that, all switches conduct a lagging current, so all of them are turned on at the ZVS condition.

The capacitor CC is the primary- side capacitor, used to block DC current flow through the IT, connecting the left leg of the full-bridge converter to the IT, assumed large enough to have an approximately zero impedance at the switching frequency in the steady state condition. Auxiliary capacitors C1 to C4 are used to provide ZVS performance of the full-bridge switches. Ca and Cb are assumed as the parasitic capacitors of the cycloconverter switches. Presuming Cf to be large, the filter capacitor and the load can be supplanted by a DC voltage Vo during each cycle of operation.

The filter inductor Lf, used to convert energy, is required to obtain ZVS operation of the primary side switches. The inductor current If is not constant during a switching period. Resonance frequency of Cf
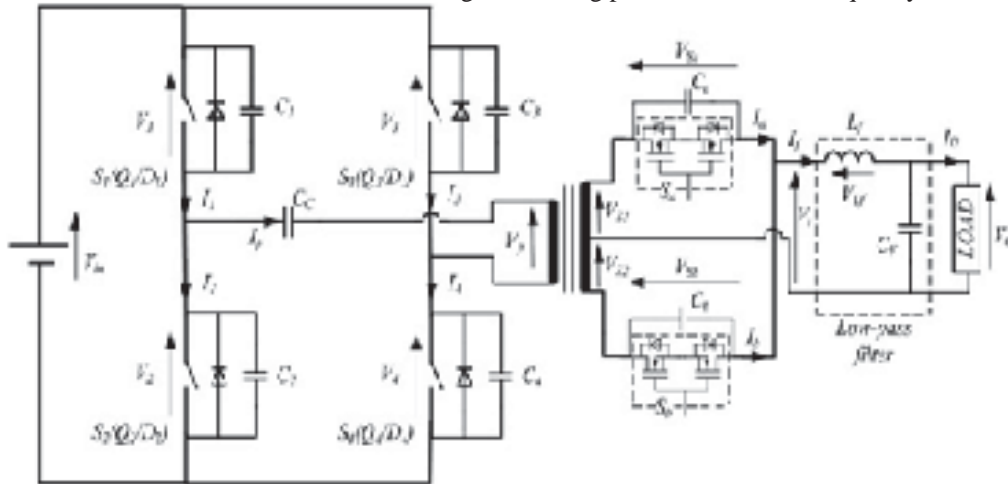

Figure 1 Proposed PWM full-bridge ZVS converter

and Lf is selected far lower than the switching frequency of the converter, and so their effects on the output voltage is negligible.

B. Control principle –

The Driving signals, fed to full bridge converter switches, are illustrated in Fig. 1. The gate signals of the bi-directional switches of the Cycloconverter are defined by the following flowchart, shown in Fig. 2.

As can be seen from the flowchart, if the reference signal sign is being positive, the gate signal of S3 will be led to Sb; otherwise, the gate signal of S4 will be conducted to Sb. The same explanation could be carried out for Sa. It should be mentioned that, the gate signals of Sa and Sb are expanded a little to achieve ZVS transition for both turn-on and turn-off operations of them. Practically, because of inevitable delay of gate driver circuits, this overlapped switching in the Cycloconverter happens naturally. Nevertheless, by imposing a suitable delay in control signals of S1 to S4, overlapping is avoided at the full bridge converter.
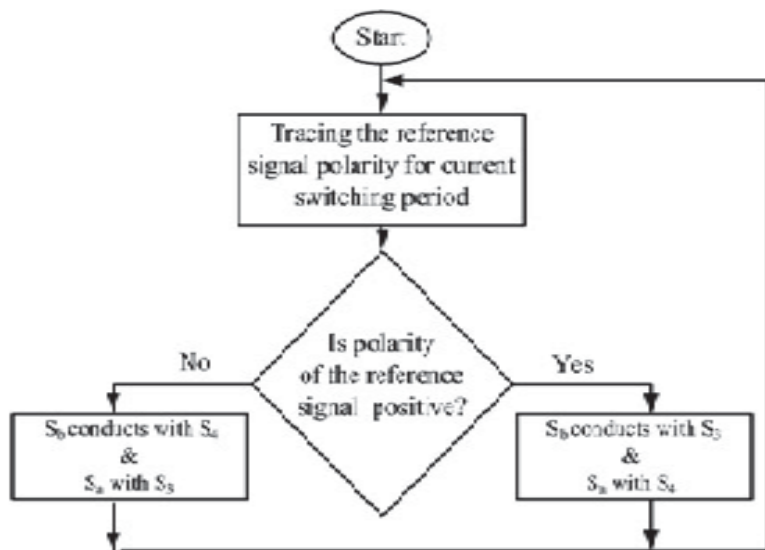
Figure 2 Proposed flow chart to produce the gate signals of the bi-directional switches

C.Calculations of output filter parameters

   The design procedure to select the value of output filter inductor (Lf) is presented in this section. A designing example is also given to consummate understanding of the procedure. Design for the rest of the power circuit is not discussed as it is very simple and already has been conducted in several papers extensively.

D. *Evaluating of the minimum value of L_f*

   An important basic criterion for soft switching operation of the full-bridge switches is the prior conduction of the anti-parallel diodes of the switches before the pulse gate of the switches is applied. This requires that, If flows in both directions during each time period. To satisfy this, the following definition is given

$$\frac{|\Delta I_f|}{2} = K_i |I_o| \quad ; \quad K_i > 1 \qquad (1)$$

where Io is the average output current, ΔIf is the peak-to-peak inductor current and Ki the equivalent coefficient which is discussed later. Assuming the entire ripple component in If flows through the capacitor and its average component flows through the load resistor, in the steady-state condition, the equations of one cycle of converter operations are given as follows

$$L_f \Delta I_f = V_f \Delta t \qquad (2)$$

$$V_f = V_s - V_o \qquad (3)$$

$$V_o = DNV_{in} \qquad (4)$$

$$V_s = NV_{in} \qquad (5)$$

$$\Delta t = T_{on} = \frac{DT_s}{2} \qquad (6)$$

Therefore from the foregoing equations, the peak-to peak inductor current Δ*If* is

$$\Delta I_f = \frac{1}{L_f}\left[(1-D)\frac{T_s}{2}\right]\left[DNV_{in}\right] \qquad (7)$$

Substituting (1) into (7) and rearranging, the output filter inductance can be achieved as

$$L_f = \frac{1}{2K_i I_o}\left[(1-D)\frac{T_s}{2}\right]\left[DNV_{in}\right] \qquad (8)$$

The relationship between the average output current Io and average output voltage Vo can be expressed as

$$I_o = V_o Y(\omega_o);$$

$$Y(\omega_o) = \begin{cases} \dfrac{1}{R_o} & \text{for DC output} \\ \dfrac{1}{|Z_o(\omega_o)|} & \text{for sinusoidal ouput} \end{cases} \qquad (9)$$

Where w_o, Z_o and Ro are the output angular frequency, load impedance and load resistance, Respectively. From (9) and (4) we have

$$I_o = NDV_{in} \cdot Y(\omega_o) \qquad (10)$$

Therefore from the foregoing equation, (8) can be rewritten as

$$L_f = \frac{1}{2K_i NDV_{in} \cdot Y(\omega_o)}\left[(1-D)\frac{T_s}{2}\right]\left[DNV_{in}\right]$$

$$= \frac{(1-D)T_s}{4K_i \cdot Y(\omega_o)} \qquad (11)$$

by regarding (11) and assuming D = Dmax, the minimum value of the output inductance (Lf*) is expressed as

$$L_f^* = \frac{(1-D_{max})T_s|Z_o(\omega_o)|}{4K_i} \qquad (12)$$

III. SIMULATION RESULTS

1. PROPOSED CIRCUIT

  The Fig 2.1.shows the proposed circuit diagram. The full bridge inverter output voltage is shown in Fig 2.2.The driving pulses for the Mosfet switch M2 and M4 and the output voltage of the Cycloconverter are shown in Fig 2.3 and Fig 2.4.The waveform of the output current of Cycloconverter is shown in Fig 2.5.
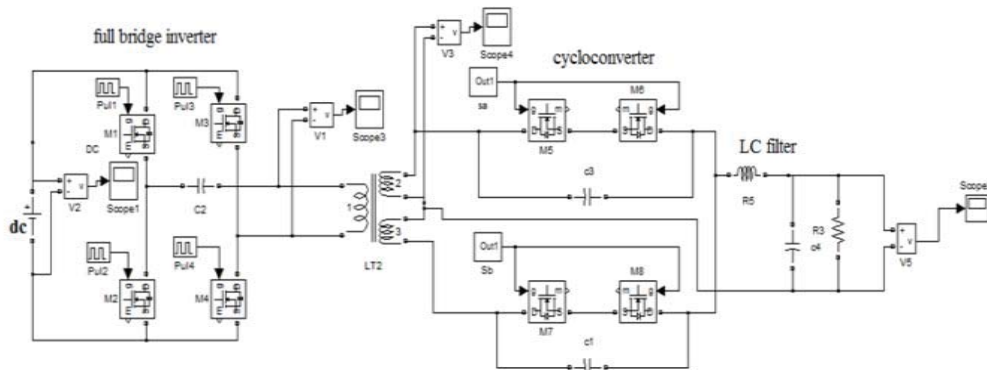

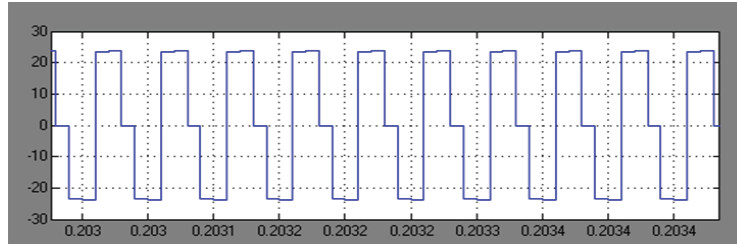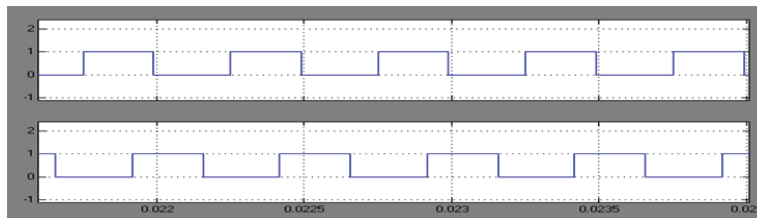Figure 2.1 Proposed Circuit Diagram

Figure 2.2 PWM inverter output voltage

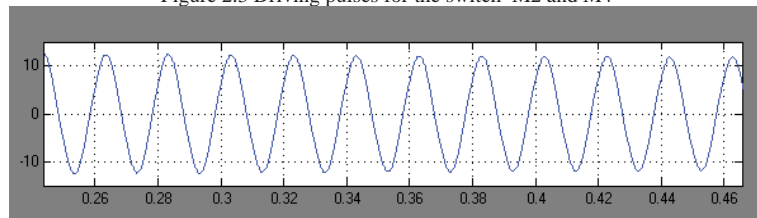Figure 2.3 Driving pulses for the switch M2 and M4

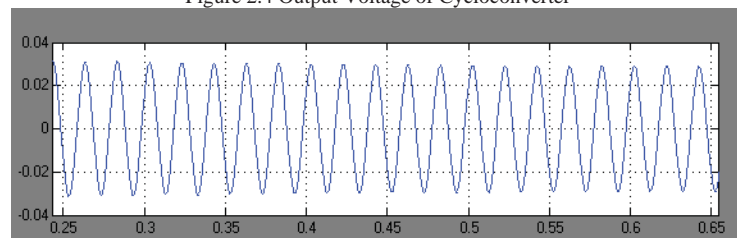Figure 2.4 Output Voltage of Cycloconverter

Figure 2.5 Cycloconverter output current

IV. CONCLUSION

In this paper a new topology of ZVS full-bridge converter which utilizes a Cycloconverter with bidirectional switches at the secondary side of the IT, has been proposed. Therefore, this DC-AC inverter achieves improved characteristics than the other converters proposed previously.

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