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새로운 영전압 스위칭 이단방식의 고역률 컨버터

노 정욱*,문 건우,정 영석,윤 명중
한국과학기술원

Novel Two Stage AC-to-DC Converter with Single Switched Zero Voltage Transition Boost Pre-Regulator using DC-Linked Energy Feedback

Chung-Wook Roh*,Gun-Woo Moon,Young-Seok Jung,and Myung-Joong Youn
Dept.of E.E in KAIST

Abstract : A novel two stage soft-switching ac-to-dc converter with power factor correction is proposed. The proposed converter provides zero-voltage-switching (ZVS) condition to main switch of boost pre-regulator without auxiliary switch. Comparing to the conventional two stage approach(ZVS-PWM boost rectifier followd by off-line ZVS dc-dc step down converter), the proposed approach is simple and reducing EMI noise problem. A new simple DC-linked energy feedback circuit provides zero-voltage-switching condition to boost pre-regulator without imposing additional voltage and current stresses and loss of PWM capability. Operational principle, analysis, control of the proposed converter together with the simulation results of 1KW prototype are presented.

1. Introduction

With the adoption of standards such as IEC555-2, there is a need to develop a converter which can perform harmonic rectification, power factor correction, isolated DC-DC conversion, and tight output voltage regulation. To meet this purpose, the power converter unit consists of a Power Factor Correction (PFC) preregulator followed by a DC-DC converter. With these two stages in cascade, the input power factor correction and the output regulation can be done independently, and there is no contradiction between them.

The most popular PFC topology is the boost converter operated in the continous conduction mode, but there are several problems that limit the effectiveness of this approach , the most notable being the switching losses of the boost switch. Several zero-voltage-transition (ZVT) boost converters [1]-[2] have been proposed in recent years to try to correct this problem. These converters behave exactly like PWM converters except for certain short switching intervals when they behave as resonant converters.

For the purpose of tight output voltage regulation, there is a need to use downstream DC-DC converter such as half bridge converter or full bridge converter, followed to PFC boost converter. Moreover, main boost configuration disadvantages such as an absence of isolation and overcurrent protection are smoothed by relating these fuctions to downstream converter.

As in the case of PFC boost converter, high frequency operation of the DC-DC converter requires a substantial reduction of switching losses. A number of soft-switching technologies for the DC-DC converter have been proposed [3-4]. Among them, the asymmetrical duty cycle conversion technique for a bridge-type PWM converter can eliminate switching losses with no increase in conduction loss [4]. With this asymmetric duty cycle conversion technique, high efficient downstream DC-DC converter with small size and weight can be constructed.

The most common construction of two stage AC-DC converter is completely separated boost converter to attain high power factor followed by a downstream DC-DC converter to produce the regulated DC output as shown in Fig.1. There have been a great deal of researches on the subject about two stage ac-dc power converter[1-5]. As a result, for both of the boost pre-regulator and the downstream DC-DC converter, effective soft switching techniques were well established[4,5]. The Zero-voltage-transition(ZVT) PWM boost converter[1] and ZVS full-bridge PWM DC/DC converter[4,5] can be effectively used for each application due to their distinctive advantage such as effective ZVS, minimum device voltage and current stresses,simple circuit topology, etc. For its reliability, this approach is well suited for high power application such as distributed power system, battery charger,and uninterruptible power supply,etc. But, its overall system is rather complex because both have auxiliary circuit for ZVS, control circuits, and sensing circuits, etc. Moreover, the auxiliary switch for boost pre-regulator can cause a severe EMI problem due to its hard switching characteristic.

In this paper, a novel two stage AC-DC converter with single switched zero voltage transition boost pre-regulator using DC-linked energy feedback is proposed. Power factor correction is provided for the first time by employing a boost pre-regulator operated in the continous conduction mode, while tight output voltage regulation is provided independently through two parallel half-bridge DC-DC converter. By using DC-linked energyfeedback concept, Zero voltage switching of the boost pre-regulator can be achieved without any auxiliary switch. Zero-voltage switching of two half bridge DC-DC converter can be achieved by adopting the asymmetrical duty ratio control technique[3].

Description of the proposed circuit and principle of operation are given in Section 2. Novel features and characteristics are outlined in Section 3. In Section 4, current programmed asymmetrical control of two half-bridge DC-DC converter is proposed. Controller implementation problem of the proposed converters is covered in Section 5, while simulation and experimental results which verify the validity of proposed converter are given in Section 6. Conclusions are summarized in Section 7.

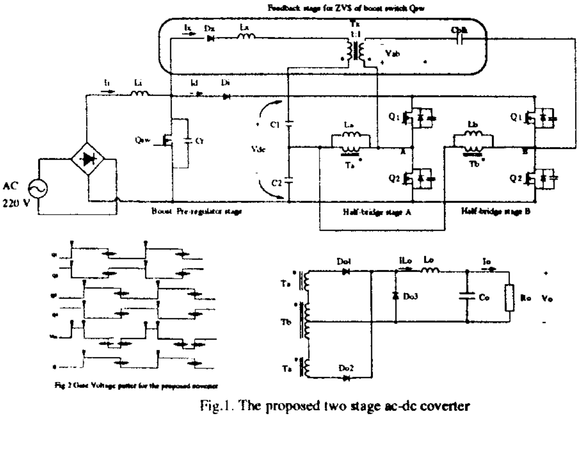

Fig.1. The proposed two stage ac-dc coverter

2. Circuit Description and Principle of Operation

The basic configuration of the proposed two stage ac-dc converter with dc-linked energy feedback is shown in Fig. 1. The proposed converter units consists of boost topology as a PFC pre-regulator and two paralleled ZVS-PWM half-bridge converter topology as a downstream dc-dc converter. MOSFETs are used in this case as the main switches Q1~Q4 for dc-dc converter, and Qb for boost converter. C1 and C2 are the low frequency energy storage capacitors and La and Lb are linear inductors to obtain a stable zero-voltage-switching operation of Q1~Q4. The proposed converter differs from a conventional two stage ac-dc converter by possesing an additional resonant network consisting of a resonant inductor (Lx), a diode (dx), and auxiliary transformer (Tx). This additional resonant network, we call this dc-linked energy feedback circuit, is activated only when there is a voltage feedback pulse Vab. Note that there is a constant phase shift between two paralleld ZVS-PWM half-bridge converter A and B. This phase shift operation can produce voltage feedback pulse Vab, which is used to obtain a stable zero-voltage-switching operation of Qb, the boost power switch as will be explained later in this section.

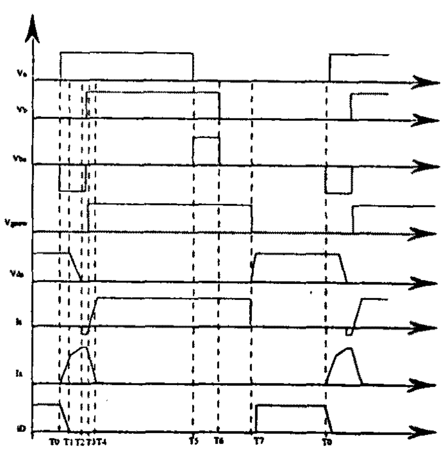

Fig.3. The kew waveforms for the proposed boost coveter stage

Fig. 2 shows the gate drive voltages Vgs1-4 of switches Q1-4, voltage feedback pulse Vab, and gate drive voltage Vgsq of boost power switch Qb. As shown in Fig. 3, just before turning on the boost switch Qb, the voltage pulse Vab must be negative one with fixed pulse width for proper operation of the proposed converter. This requirement will be satisfied if the clock of the boost converter controller is synchronous to that of ZVS-PWM half-bridge converter A.

Figure 3 illustrates the topological states and Fig. 4 the key waveforms for the boost pre-regulator stages of the proposed converter. For this description of circuit operation (and for the subsequent development of a design procedure in the next section), the following assumptions are made:

* two paralleled ZVS-PWM half-bridge dc-dc converter is assumed a constant power source
* Input filter inductance is large enough to considered as current source Ii
* All devices and components are ideal
* Turn ratio of auxiliary transformer Tx is n

The analysis of the downstream dc-dc converter stages will not covered in this paper, but is explained detailed in [3]. The sequence of topological states is described below:

(a)T0 - T1 : Prior to T0, the main switch (S) is off and the voltage feedback pulse Vab is zero, and the rectifier diode (D) is conducting. At T0, Vab is negative (Vx = -nVo) and Dx conducts. The Lx current linearly ramps up until it reaches Ii at T1, where D is turned off with soft-switching. This time interval, t01, is given by:

$$t_{01} = L_r \frac{I_i}{V_o}$$

(b)T1-T2 : Lx current continues to increase due to the resonance between Lx and Cr. Cr is discharged until the resonance brings its voltage to zero at T2, where the anti-parallel diode of S starts to conduct. This resonant time period t12 is :

$$t_{12} = \frac{\pi}{2}\sqrt{L_r C_r}$$

(c)T2-T3 : The anti-paralle diode of S is on. To achieve ZVS, the turn-on signal of S should be applied while its body diode is conductiong. Besides, the pulse width of the Vab, (or, phase delay between two ZVS-PWM half-bridge converter operation), t_{AB} has to satisfy the following inequality:

$$t_{AB} \geq L_r \frac{I_i}{V_o} + \frac{\pi}{2}\sqrt{L_r C_r}$$

(d)T3-T4 : At T3, Vab is zero, and main switch (S) is on with zero-voltage switching operation. The energy stored in the resonant inductor (Lx) is transfered to the constant power source. Lx current decreases linearly until it reaches zero at T4.

(e)T4-T5 : Dx is turned off at T4. The operation of the circuit at this stage is identical to that of the PWM boost converter.

(f)T5-T6 : At T5, the voltage feedback pulse Vab is positive with varying width (Vx = nVo), but diode Dx is still off. Hence, the circuit operation is independent of the positive Vab.

(g)T6-T0 : This interval is identical to the freewheeling stage of the boost PWM converter. At T0, The Vab is positive again, starting another switching cycle.

One switching cycle is completed at the end of mode 8. It can be seen that the basic operation and waveforms are very similar to those of the ZVT-PWM boost converter[1].

3. Novel Features and Characteristics

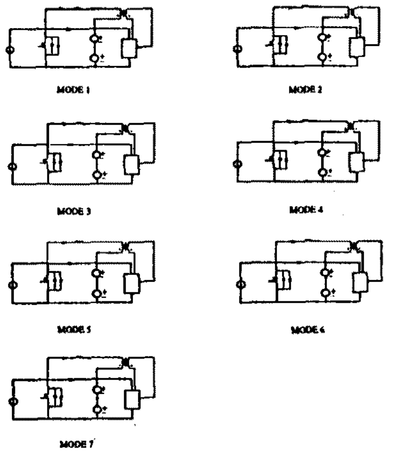

Fig. 4. Topological circuits for the proposed boost pre-regulator stage

A. Conserved ZVT-PWM boost converter Characteristics

In the proposed converter, it can be seen that the resonant network is activated only during switching instants and the equivalent topology states of the proposed boost pre-regulator stage are same as those of the ZVT-PWM boost converter[1]. As a result, the switching waveforms of the main devices are almost same as those of the PWM converter and the PWM operation is always possible. All devices including auxiliary devices are subjected to minimum voltage and current stresses and the ZVS is maintained for the whole load and line range. Therefore, almost all of characteristics of the conventional hard switching PWM converters are conserved in the proposed converter and thus, most of modelling, design, and control technique for PWM converters can also be used for the proposed boost pre-regulator stage.

B. ZVS of boost pre-regulator without auxiliary switch

In the proposed converter, zero-voltage-switching operation of boost pre-regulator switch can be achieved without auxiliary switch. As a result, an any driver or a controller for auxiliary switch is not needed in the proposed boost pre-regulator stage. Moreover, EMI noise problem due to hard switching characteristics of auxiliary switch for ZVT-PWM boost converter can be eliminated.

C. ZVS-PWM half bridge converter for dc-dc conversion

The proposed converter uses ZVS-PWM half bridge topology for downstream dc-dc stage for galvanic isolation and tight output regulation. Complementary of asymmetrical control of ZVS-PWM half bridge topology is intended to achieve ZVS just with a small inductor in series with the transformer, composed in part or in full by the transformer leakage inductance. High efficiencies are obtained in this topology thanks to the ZVS capability. The only drawback of this topology is its sensitivity to input voltage variation, which is already overcome in the proposed converter scheme with boost pre-regulator stage.

4. Simulation results

In order to verify the operational principles and test the performance of the proposed two stage ac-dc converter. The computer simulation is done by using Pspice with the parameters as listed in Table 1.

Table 1. Parameters used in Simulation.

Output Voltage (Vo)	48VDC
Output Power (Po)	500W
Half-Bridge Resonant Inductors (La1,Lb1)	22uH
Boost Resonant Inductor (Lx)	20uH
Boost Resonant Capacitor (Cr)	3.3nF
Nominal Line Voltage (Vac)	110 VAC
Input inductor (Li)	1mH
Bulk Capacitor (C1,C2)	220 uF
Output Inductor (Lo1,Lo2)	200uH
Output Capacitor (co)	100uF
Half-Bridge Transformer Turn Ratio(N)	2
Auxiliary Transformer Turn Ratio (n)	1.1
Switching Frequency (fs)	100Khz

Fig. 5 shows waveforms of input inductor current and resonant inductor current, switch voltage and gate voltage, voltage feedback pulse, and rectifier diode current and auxiliary primary currents for boost pre-regulator stage of the proposed converter. It can be seen that all waveforms are well matched with the theoritical ones. Fig. 6 shows the waveforms of gate voltages and switch voltages , primary currents, and output inductor currents for downstream dc-dc converter stage. It shows that dc-linked energy feedback circuit does not affect dc-dc converter operation. Fig. 7 shows the waveforms of input voltage and current and output voltage. In can be seen that the input current waveforms show sinusoidal waveforms keeping in phase input voltage, while the output voltage is regulated to the reference voltage 48VDC with tight regulation. The proposed converter does not have 120Hz ripple in the output voltage, hence, it can be used for wide application such as distributed power system,battery charger,etc.

5. Conclusion

A novel two stage ac-dc converterwith single switched zero voltage transition boost pre-regulator using dc-linked energy feedback is proposed. Operation,analysis and control of the proposed converter are described and computer simulation is done with 1KW power level. It is shown that the proposed converter provides both of input power factor correction and tight regulated output voltage with isolation with two stage. The proposed converter has same characteristics of ZVT boost converter at the boost pre-regulator stage without any auxiliary switch. Due to distinctive advantages including simple topology, high effieciency, and effective ZVS, low EMI, Minimum device voltage and current stresses and PWM capability, the proposed converter can be thought to be effectively used for high power, high frequency power factor correction circuit, especially for line converter in distributed power supply systems.

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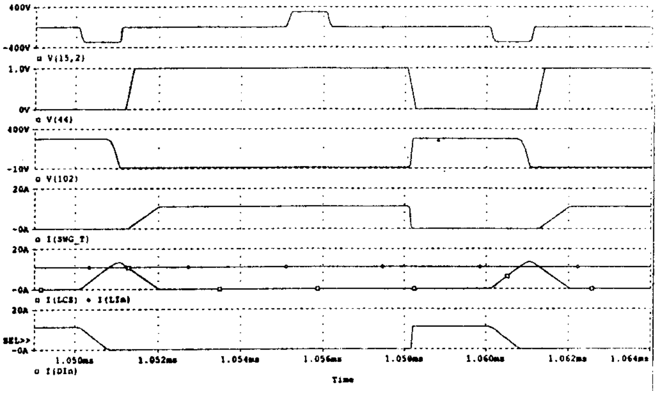

Fig. 5. Waveforms of the proposed boost pre-regulator stage

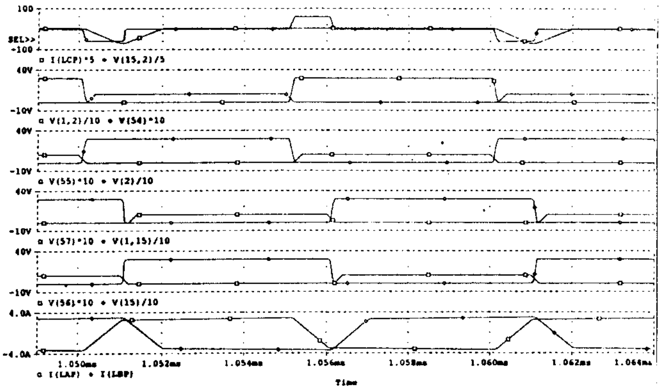

Fig. 6. Waveforms of the downstream DC/DC converter stage