고전력밀도 단일전력단 교류/직류 컨버터

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An Integrated Single Stage AC/DC Converter

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Abstract

A study on an integrated single stage AC/DC converter is presented in this paper. The input current can be controlled by the auxiliary winding(L_{aux}), auxiliary primary winding(N_3), and the boost inductor(L_B) which are designed to operate in discontinuous conduction mode(DCM) to reduced the total harmonic distortion(THD) of input current. The auxiliary primary winding(N_3) is critically selected in order to compress the input capacitor voltage(V_{in}) as well as to reduce the current stress of the switch(Q).

Low total harmonic distortion(THD), low input voltage(V_{in}) in universal input voltage(V_{AC}), low current stress at the switching device and high efficiency are the main consideration keys in this design to achieve high performance system with low cost of single stage AC/DC converter. A 30W single stage AC/DC prototype converter is under study.

1. Introduction

Power supplies can be found in all electronic products. It is used to convert AC voltage to high or low DC voltage as electronic products requirement. Usually, power supplies contain of two stages which is the sum of AC-DC converter and DC-DC converter as shown in Fig. 1. AC-DC converter is the first stage which is commonly constructed by bridge diode rectifiers to convert AC voltage to DC voltage, PFC converter using boost inductor steps up the rectified voltage to around 380-400VDC as well as to improve the power factor(PF) and its energy is stored in the input capacitor(C_{in}). And the second stage is DC/DC converter which is used to step up or step down the voltage as output load requirement. Controllers are applied for the two converters independently. Even though this system can meet the IEC 61000-3-2 for the total harmonic distortion(THD) regulation, but it composed of two converters which means that it has more components. Therefore, the cost increases which is the main drawback for the two stage AC/DC converter system.

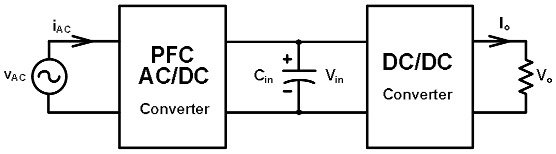


Fig. 1. Two stage AC/DC converter

Nowadays, single stage AC/DC converter is very popular topic for power supplies applications. Because, the two stages are combined into one stage that can make the system more compact, less components, and simple controller for single switch which results in low cost. And a lot of single stage topologies have been studied[1,2]. And to improve power factor(PF), auxiliary winding or capacitor are applied as in conventional topology[3,4].There are four main factors must be considered in single stage AC/DC converter; PF, V_{in}(Input capacitor(C_{in})), switching voltage stress and efficiency.

2. Proposed Single Stage AC/DC Converter

In this paper, single stage AC/DC converter composed of additional auxiliary part in order to improve power factor(PF) and input current wave shaping by reducing the total harmonic distortion(THD) is proposed[5]. The boost inductor is operated in discontinuous mode (DCM). The auxiliary primary winding (L_{aux}) is coupled with flyback transformer as shown in Fig. 2. Moreover, the conduction losses can be reduced comparing to the conventional converter [1] because the current flows through only the three diodes(two bridge diodes & an auxiliary diode) in the primary side.

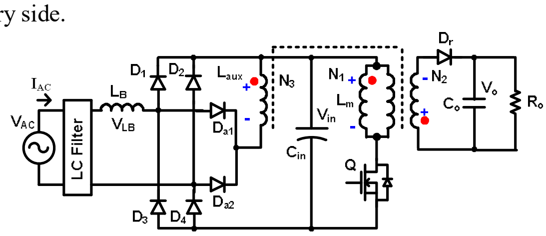


Fig. 2. Proposed AC/DC Single Stage Converter

2.1 Operation Mode

The waveform of the operation mode is expressed as in Fig. 3 below. It is divided into main four modes and each operation mode described detail as shown in Figs. 4(a)-(d).

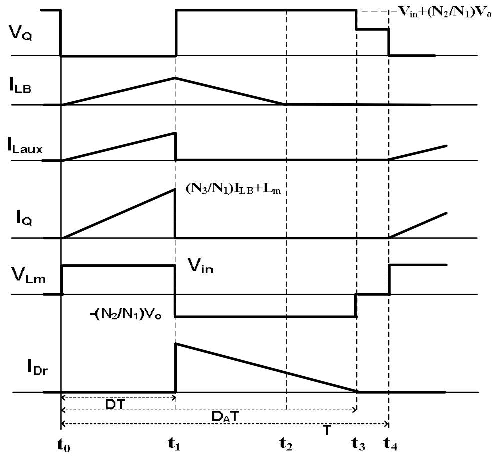
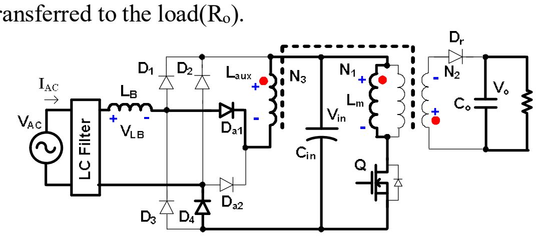


Fig. 3 Operation waveforms

Mode 1: t_o-t_1

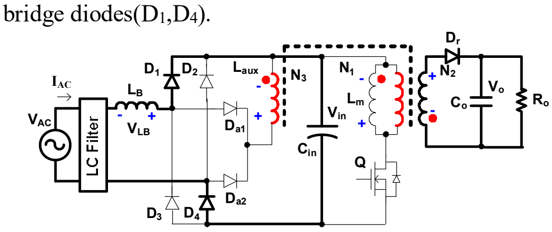
When the switch(Q) is turned on, the energy starts to store in magnetizing inductance(L_m), boost inductor(L_B) and the auxiliary primary winding(L_{aux}) as the current increases linearly shown in Fig.3. Since the rectified diode(D_r) of the secondary side is reversed biased, so only the stored energy in output capacitor(C_o) is transferred to the load(R_o).



(a) t_o-t_1

Mode 2: t_1-t_2

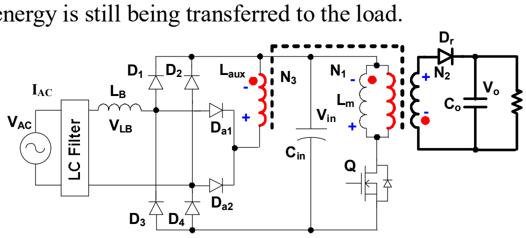
When the switch(Q) is turned off, the polarities of the primary and secondary changed, so the energy is transferred to the load as the secondary rectified diode is forward biased. Since the auxiliary diodes(D_{a1},D_{a2}) is reversed biased, therefore only negative voltage is induced at the auxiliary primary winding(L_{aux}). The energy in boost inductor(L_B) is reset to input capacitor(C_{in}) flowing through the bridge diodes(D_1,D_4).



(b) t_1-t_2

Mode 3: t_2-t_3

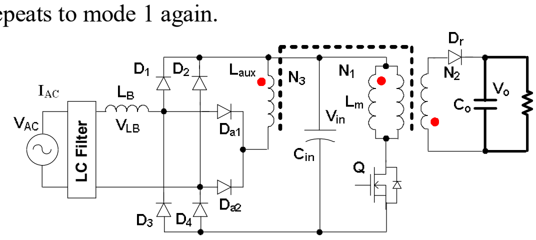
In this stage, the voltage of input capacitor is equal to the sum of AC voltage(V_{AC}) and boost inductor voltage(V_{LB}) which means that the stored energy in boost inductor is completely reset. And the energy is still being transferred to the load.



(c) t_2-t_3

Mode 4: t_3-t_4

In this case, the stored energy in magnetizing inductance(L_m) is completely demagnetized. Therefore, the voltage of the secondary inductance becomes zero and the stored energy in the output capacitor(C_o) is transferred to the load. After this stage is finished, it repeats to mode 1 again.

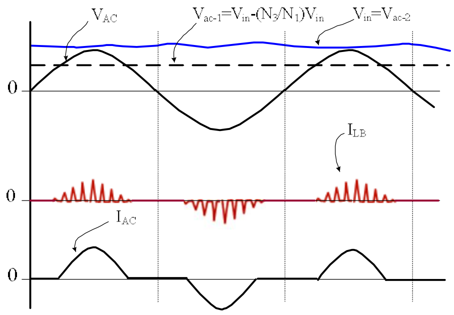


(d) t_3-t_4

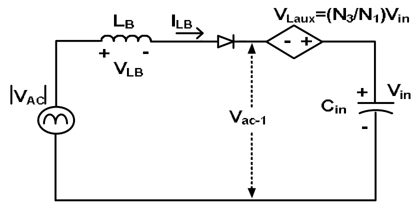
Fig. 4. Operation modes(a)-(d)

2.2 Circuit Analysis

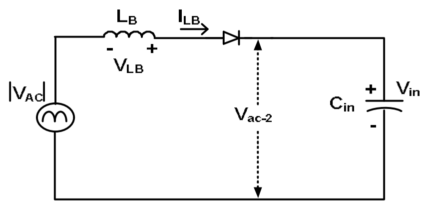
The equivalent circuit in Fig.2 can be simplified as Figs. 5 (b) and (c) according to the turn on and turn off of the switch(Q) respectively.



(a). Operation mode waveforms



(b). Switch Q turned on



(c). Switch Q turned off

Fig. 5. (a) Operation mode waveforms , (b)/(c) Equivalent ciricuts

As the switch(Q) is turned on, the auxiliary primary winding(L_{aux}, N_3) is series connected with AC input voltage and boost inductor(L_B). Therefore, the voltage induced on the boost inductor(V_{LB}) can be expressed as Eq. (1). Even though the sum of the AC input voltage(V_{AC}) and auxiliary primary winding voltage(V_{Laux}) is low, the current still can flow through the boost inductor(L_B), auxiliary diodes(D_{a1}/D_{a2}) and input capacitor(C_{in}) which means that the energy stores in the boost inductor(L_B). And the current that flows through the switch(Q) in this mode is the sum of magnetizing current(I_{Lm}) and boost inductor current((N_3/N_1)I_{LB}) as shown by Eq.(2).

$$V_{LB} = |V_{AC}| + V_{Laux} - V_{in} \tag{1}$$

Where, V_{Laux}=(N_3/N_1)V_{in}

$$I_Q = (N_3/N_1)I_{LB} + I_{Lm} \tag{2}$$

Where, $I_{LB} = \left(\frac{|V_{AC}| + V_{Laux} - V_{in}}{L_B}\right)DT$, $I_{Lm} = \frac{V_{in}}{L_m}DT$

D: Duty ratio , T: switching period

When the switch is turned off, the polarities of the transformer as well as the auxiliary primary winding(L_{aux},N_3) changed that makes auxiliary diodes(D_{a1}/D_{a2}) becomes reverse biased.

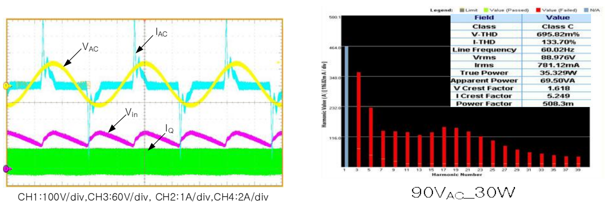
Therefore, the stored energy in the boost inductor(L_B) is reset to the input capacitor(C_{in}) through the bridge diodes. The voltage and current of the boost inductor can be expressed as the following equations.

$$V_{LB} = |V_{AC}| - V_{in} \qquad (3) \qquad\qquad I_{LB} = \frac{|V_{AC}| - V_{in}}{L_B} \qquad (4)$$

In order to reduce the total harmonic distortion(THD), the boost inductor(L_B) and flyback converter is operated in discontinuous mode(DCM) [2].

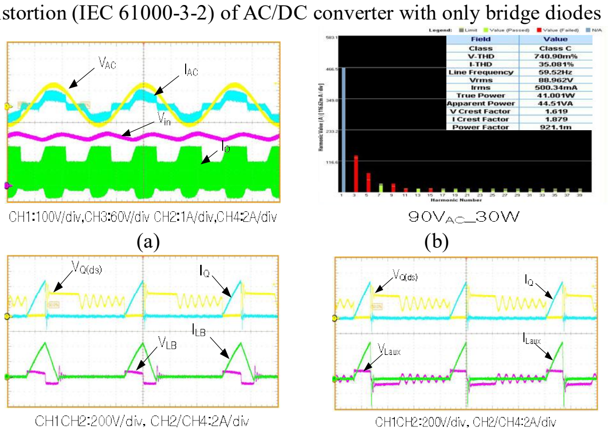
2.3 Experimental Result

To verify the possibility of the proposed single stage AC/DC converter, a 30W prototype was built and being tested. Fig. 6 shows the input voltage(V_{AC}), current(I_{AC}) and its total harmonic distortion(THD) of single stage AC/DC converter with only bridge diodes, but it is not qualified for application. As shown in Figs.6(a) and (b), the input current wave shaping is completely not sine-wave and current harmonics(3^{th}-39^{th}) are out of the limit. Therefore, single stage AC/DC converter using auxiliary primary winding(L_{aux},N_3) is proposed to improve these drawbacks. The parameters are; boost inductor L_B=33µH, magnetizing inductance $L_m(N_1)$=271.4µH and turns ratio N_3/N_1=0.66. Figs. 7(a) and (b) shows its input voltage/current waveform(V_{AC}/I_{AC}) and total harmonic distortion respect to the IEC 61000-3-2 standard under input voltage(V_{AC})=90V_{AC},output power of 30W and 19V output voltage condition. Both boost inductor and flyback converter are operated in DCM as shown in Figs. 7(c) and (d). The input current wave shaping and power factor of the proposed converter is much better, even though some of the current harmonics are out of the limit.



(a) (b)

Figs.6 (a) AC input voltage (V_{AC}) and current (I_{AC}), (b) Total harmonic distortion (IEC 61000-3-2) of AC/DC converter with only bridge diodes



(c) (d)

Figs.7 (a) AC input voltage (V_{AC}) and current (I_{AC}),
(b) Total harmonic distortion (IEC 61000-3-2),
(c) Switch (Q) voltage/current and inductor voltage and current (L_B),
and (d) auxiliary primary winding(L_{aux})

3. Conclusion

In this paper, single stage AC/DC converter which is applicable for lighting equipment (P_o>25W) is presented. The power factor (PF) is 91.2%, but the total harmonic distortion is not yet qualified to the IEC 61000-3-2 class C standard. So the solution for class C total harmonic distortion and the possibility of single stage AC/DC converter topology for adaptor application (120W) become the next future project.

ACKNOWLEDGMENT

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