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SINGLE POWER CONVERSION AC-DC CONVERTER WITH HIGH POWER FACTOR BASED ON ZVZCS

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ABSTRACT

A single power-conversion ac–dc converter with high power factor based on zvzcs. The proposed converter is derived by integrating a full-bridge diode rectifier and a series-resonant active-clamp dc–dc converter. To obtain a high power factor without a power factor correction circuit. The proposed converter provides single power-conversion by using the novel control algorithm for both power factor correction and output control. Also, the active-clamp circuit clamps the surge voltage of switches and recycles the energy stored in the leakage inductance of the transformer. Moreover, it provides zero-voltage turn-on switching of the switches. Also, a series-resonant circuit of the output-voltage doubler removes the reverse-recovery problem of the output diodes. The proposed converter provides maximum power factor 0.995Nand maximum efficiency of 95.1% at the full load. The operation principle of the converter is analyzed and verified. Experimental results for a 400 W ac–dc converter at a constant switching frequency of 50 kHz are obtained to show the performance of the proposed converter. *Index Terms*—Active-clamp circuit, series-resonant circuit, single power-conversion.

1.INTRODUCTION

Generally the ac–dc converter consists of a full-bridge diode rectifier, a dc-link capacitor and a high frequency dc–dc converter. These converters absorb energy from the ac line only when the rectified line voltage is higher than the dclink voltage. Therefore, these kinds of converters have a highly distorted input current, resulting in a large amount of harmonics and a low power factor. To solve the harmonic pollution caused by ac–dc converters, a number of power factor correction (PFC) ac–dc converters have been proposed and developed [1]–[8]. The PFC ac–dc converter can be implemented by using two power-processing stages. The PFC input stage is used to obtain high power factor while maintaining a constant dc-link voltage. Most PFC circuits employ the boost converter [9]– [15]. The output stage, which is a high frequency dc–dc converter, gives Manuscript received June 26, 2013; revised September 1, 2013; accepted October 9, 2013. Date of current version April 30, 2014. This work was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science, and Technology (Grant 2012R1A1A2008890). Recommended for publication by are with the Department of Electrical Engineering, In general, the PFC ac–dc converter can be categorized into two types: two-stage ac–dc converters [16], [17] and single stage ac–dc converters [18]–[27]. Two-stage ac–dc converters consist of two power-processing stages with their respective control circuits. However, two-stage ac–dc converters raise power losses and the manufacturing cost, eventually reducing the system efficiency and the price competitiveness. In efforts to reduce the component count, the size, and the cost, a number of single-stage ac–dc converters have been proposed and developed. The main idea is that a PFC input stage and a high frequency dc– dc converter are simplified by sharing common switches so that the PFC controller, the PFC switch, and its gate driver can be eliminated. Most single-stage ac–dc converters in low-power application employ single-switch dc–dc converters such as fly back or forward converters [20]–[23]. These converters are simple and cost-effective. However, they have high switching power losses because of the hard-switching operation of the power switch. Thus, to overcome the drawback, single stage ac–dc converters based on the asymmetrical pulse width modulation (APWM) half-bridge converter have been proposed in [24]–[27]. They have low switching losses because of the zero-voltage switching (ZVS) operation of the power switches. However, the

conventional single-stage ac–dc converters have high voltage stresses or a low power factor in comparison with the two-stage ac–dc converter. Also, the PFC circuit used in the single-stage ac–dc converter requires the dc-link electrolytic capacitor and the inductor. The dc-link electrolytic capacitor and the inductor raise the size and the cost of the converter. To solve these problems, the dc-link electrolytic capacitor should be removed from the circuits.

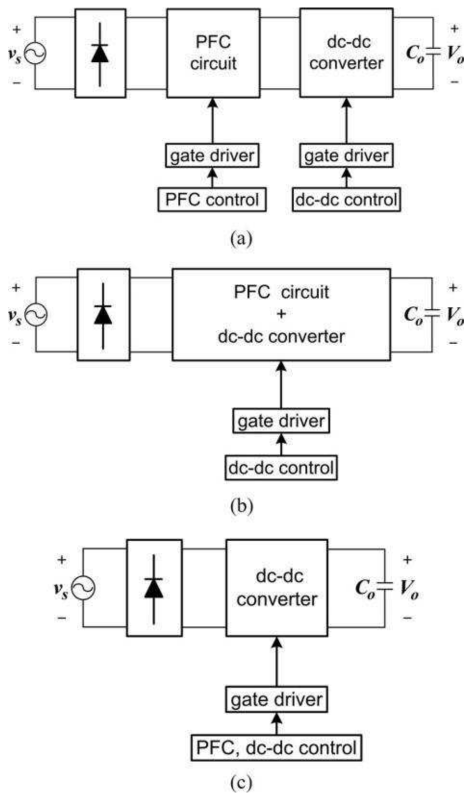


Fig 1.Block diagrams of the conventional PFC converters and the proposed converter. (a) Two-stage converter. (b) Single-stage converter. (c) Single powerconversion converter.

The approach of achieving this is through the alleviation of the pulsating component of the input power by sacrificing the input power factor [28], [29]. The main idea is to intentionally distort the input current such that there is little low-frequency power-ripple component being generated at the input. Consequently, nonelectrolytic capacitors such as film capacitors or ceramic capacitors can be used instead of electrolytic capacitors. This approach is mostly applied to single-switch PFC ac–dc converters. Compared to the conventional single-stage ac–dc converters with the dc-link electrolytic capacitor, the converters using this approach are small and cost-effective; on the other hand, they have drawbacks such as low power factor and low efficiency because of the discontinuous current mode (DCM) operation and the hard-switching operation. Therefore, these converters are attractive in low-cost and low-power application such as a light-emitting diode (LED) power supply. In view of this, the objective of this paper is to propose the single power-conversion ac–dc converter with the high power factor and the high power efficiency. The proposed converter is composed of a full-bridge diode rectifier and a series-resonant active-clamp dc–dc converter. The proposed converter provides a simple structure, a lowcost, and lowvoltage stresses because it has only high frequency dc–dc converter. To obtain high power factor without a PFC stage, a novel control algorithm is proposed. The proposed converter provides high power factor and single power-conversion by using the novel control algorithm instead of the PFC circuit. Also, the active-clamp circuit clamps the surge voltage of switches and recycles the energy stored in the leakage inductance of the transformer.Moreover, it provides ZVS operation of the switches. Also, a series-resonant circuit of the output-voltage doubler removes the reverse-recovery problem of the output diodes by zero-current switching (ZCS) operation. The design guidelines for the proposed converter are discussed and experimental results are obtained to show then performance of the proposed converter.

2.CHARACTERISTICS AND OPERATION PRINCIPLE OF THE PROPOSED AC–DC CONVERTER

A. Concept of the Single Power-Conversion AC–DC Converter

Fig. 1(a) shows the schematic diagram of the conventional two-stage ac–dc converter. It comprises a full-bridge diode rectifier, a PFC circuit, a control circuit for the PFC circuit, a high frequency dc–dc converter, and a control circuit for output control. The control circuit is composed of gate-drivers and a controller. Namely, two-stage ac–dc converters have two power processing stages with their respective control circuits. Also, the boost type PFC converter used in most PFC input stages requires the dc-link electrolytic capacitor and the inductor. Two control circuits, the dc-link capacitor and the inductor raise the size, weight and the cost of the converter and reduce the price competitiveness. On the other hand, the advantage is to decouple control of the dc-link capacitor voltage from that of the output voltage and realize much tighter output control. Therefore, two stage ac–dc converters are preferred option when reliability is more important concerns than cost per unit. Fig. 1(b) shows the schematic diagram of the conventional single-stage ac–dc converter. It comprises a full-bridge diode rectifier, a PFC circuit, a high frequency dc–dc converter, and a control circuit for output control. The PFC circuit and the high frequency dc–dc converter are simplified by sharing common switches for eliminating the PFC switch and the control circuit for the PFC circuit as shown in Fig. 1(b). That is, single-stage ac–dc converters have only one control circuit.

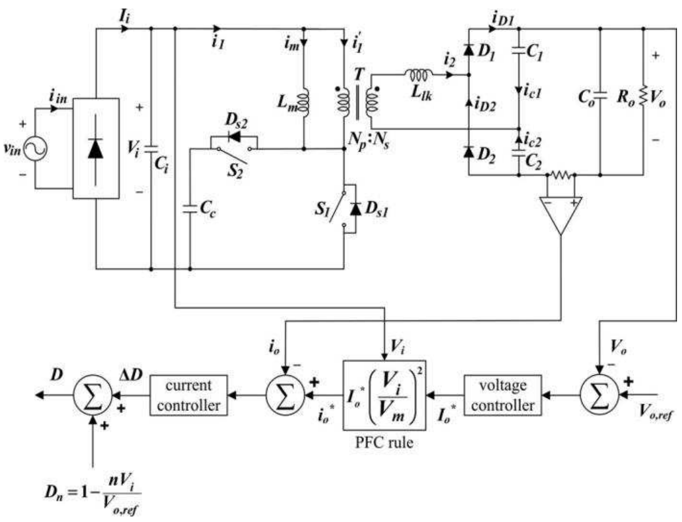


Fig 2 Proposed single power-conversion ac–dc converter and the control block diagram.

Thus, the output voltage is easily regulated by a controller and the power factor is strongly influenced by the design of the PFC circuit. However, single-stage ac–dc converters have several disadvantages. First, the power factor is also related to the controller, indicating that the variation of the load or the input voltage will change the power factor. Second, the output voltage control bandwidth is limited to a few hertz not to excessively distort the input current. Third, single-stage ac–dc converters require the dc-link electrolytic capacitor and the inductor for the PFC circuit, just like two-stage converters. Finally, the conventional single-stage ac–dc converters have high voltage stresses or low power factor in comparison with two stage ac–dc converters. Fig. 1(c) shows the schematic diagram of the single power-conversion ac–dc converter. It consists of a full-bridge diode rectifier, a high frequency dc–dc converter, and a control circuit. That is, the single power-conversion ac–dc converter has also one control circuit because it has no PFC circuit. However, it requires the control algorithm for both PFC and output control, unlike single-stage ac–dc converters. Also, it has a large ac second-harmonic ripple component reflected at the output voltage in comparison with two-stage and singlestage converters because it has no dc-link electrolytic capacitor. However, the single power-conversion ac–dc converter provides a simple structure, a low cost, and low voltage stresses because it has no PFC circuit composed of the inductor, power switching devices and the dc-link electrolytic capacitor. Therefore, the single power-conversion ac–dc converter is preferred option when the cost per unit is more important concerns than reliability. *B. Operation Principle of the ProposedCircuit* Fig. 2 shows the proposed single power-conversion ac–dc converter and the control block diagram. The high frequency dc–dc converter [30], [31] used in the proposed converter combines an active-clamp circuit and a series-resonant circuit across the power transformer *T*. The active-clamp circuit is composed of a main switch $S1$, an auxiliary switch $S2$, and a clamp capacitor Cc. The switch $S1$ is modulated with a duty ratio D and the switch $S2$ is complementary to $S1$ with a short dead time. The active-clamp circuit serves to clamp the voltage spike across $S1$ and to recycle the energy stored in the leakage inductance of the transformer *T*. Also, it provides ZVS turn-on of $S1$ and $S2$. The series-resonant circuit is composed of the transformer leakage inductance Llk, the resonant capacitors $C1$, $C2$, and the output diodes$D1$,$D2$ and provides ZCS turn-off of the $D1$ and $D2$. In order to analyze the operation principle, several assumptions are made during one switching period Ts:

1) the switches $S1$ and $S2$ are ideal except for their body diodes $D1$,$D2$ and capacitances $C1$, $C2$;

2) the input voltage $v$in is considered to be constant because one switching period Ts is much shorter than the period of $v$in ;

3) the output voltage Vo is constant because the capacitance of the output capacitor Co is sufficiently large, similarly, Cc is sufficiently large that is voltage ripple is negligible. Thus, the clamp capacitor voltage Vc is constant;

4) the power transformer *T* is modeled by an ideal transformer with the magnetizing inductance Lm connected in parallel with the primary winding Np, and the leakage inductanceLlkconnected in series with the secondarywinding Ns.

The steady-state operation of the proposed converter includes six modes in one switching period Ts. The operating modes and theoretical waveforms of the input side and the output side are shown in Figs. 3 and 4, respectively. The rectified input voltage Vi is $|v\text{in}| = |Vm\sin\omega t|$, where Vm is the amplitude of the input voltage and ω is the angular frequency of the input voltage. Prior to Mode 1, the primary current $i1$ is a negative direction and the secondary current $i2$ is zero. *Mode 1* $[t0, t1]$*:* At the time $t0$, the voltage $vs1$ across $S1$ becomes zero and $Ds1$ begins to conduct power. After the time $t0$, $S1$ is turned on. Since $i1$ started flowing through $Ds1$ before $S1$ wasturned on, $S1$ achieves the ZVS turn-on. As shown in In view of this, the objective of this paper is to propose the single power-conversion ac–dc converter with the high power factor and the high power efficiency. The proposed converter is composed of a full-bridge diode rectifier and a series-resonant active-clamp dc–dc converter. The proposed converter provides a simple structure, a lowcost, and lowvoltage stresses because it has only high frequency dc–dc converter. To obtain high power factor without a PFC stage, a novel control algorithm is proposed. The proposed converter provides high power factor and single power-conversion by using the novel control algorithm instead of the PFC circuit. Also, the active-clamp circuit clamps the surge voltage of switches and recycles the energy stored in the leakage inductance of the transformer.Moreover, it provides ZVS operation of the switches. Also, a series-resonant circuit of the output-voltage doubler removes the reverse-recovery problem of the output diodes by zero-current switching (ZCS) operation. The design guidelines for the proposed converter are discussed and experimental results are obtained to show the performance of the proposed converter.

3.ZERO VOLTAGE AND ZERO CURRENT SWITCHING :

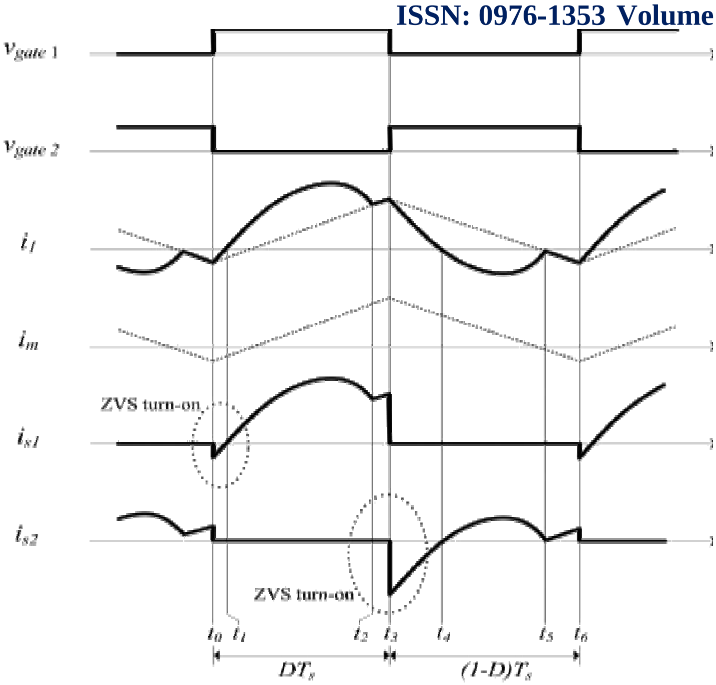
During the On-state, the switch S is closed, which makes the input voltage (V_i) appear across the inductor, which causes a change in current (I_L) flowing through the inductor during a time period (t) by the formula:

$$\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L}$$

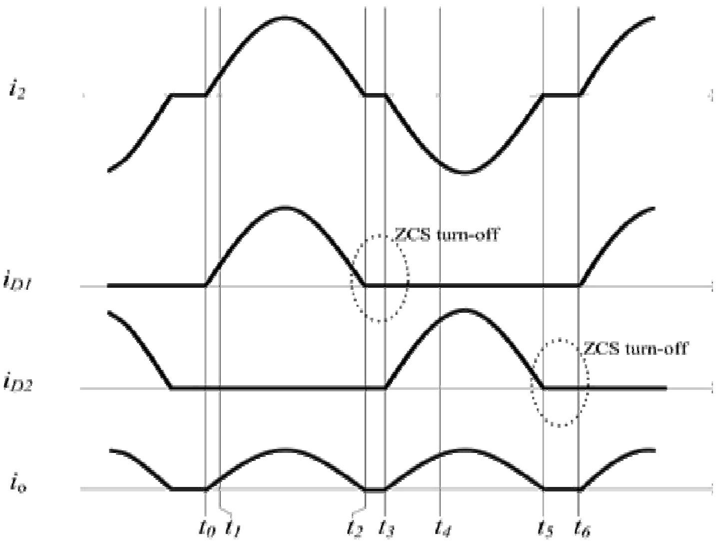
At the end of the On-state, the increase of I_L is therefore:

$$\Delta I_{L_{On}} = \frac{1}{L}\int_0^{DT} V_i dt = \frac{DT}{L}V_i$$

D is the duty cycle. It represents the fraction of the commutation period T during which the switch is on. Therefore D ranges between 0 (S is never on) and 1 (S is always on).



(a)



(b)

During the Off-state, the switch S is open, so the inductor current flows through the load. If we consider zero voltage drops in the diode, and a capacitor large enough for its voltage to remain constant, the evolution of I_L is:

$$V_i - V_o = L\frac{dI_L}{dt}$$

Therefore, the variation of I_L during the Off-period is:

$$\Delta I_{L_{Off}} = \int_{DT}^{T} \frac{(V_i - V_o)\,dt}{L} = \frac{(V_i - V_o)\,(1-D)\,T}{L}$$

As we consider that the converter operates in steady-state conditions, the amount of energy stored in each of its components has to be the same at the beginning and at the end of a commutation cycle. In particular, the energy stored in the inductor is given by:

$$E = \frac{1}{2} L I_L^2$$

So, the inductor current has to be the same at the start and end of the commutation cycle. This means the overall change in the current (the sum of the changes) is zero:

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = 0$$

Substituting $\Delta I_{L_{On}}$ and $\Delta I_{L_{Off}}$ by their expressions yields:

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = \frac{V_i D T}{L} + \frac{(V_i - V_o)(1-D)T}{L} = 0$$

This can be written as:

$$\frac{V_o}{V_i} = \frac{1}{1-D}$$

This in turn reveals the duty cycle to be,

$$D = 1 - \frac{V_i}{V_o}$$

The above expression shows that the output voltage is always higher than the input voltage (as the duty cycle goes from 0 to 1), and that it increases with D, theoretically to infinity as D approaches 1. This is why this converter is sometimes referred to as a step-up converter.

Discontinuous mode

If the ripple amplitude of the current is too high, the inductor may be completely discharged before the end of a whole commutation cycle. This commonly occurs under light loads. In this case, the current through the inductor falls to zero during part of the period (see waveforms in figure 2.7). Although slight, the difference has a strong effect on the output voltage equation. It can be calculated as follows:

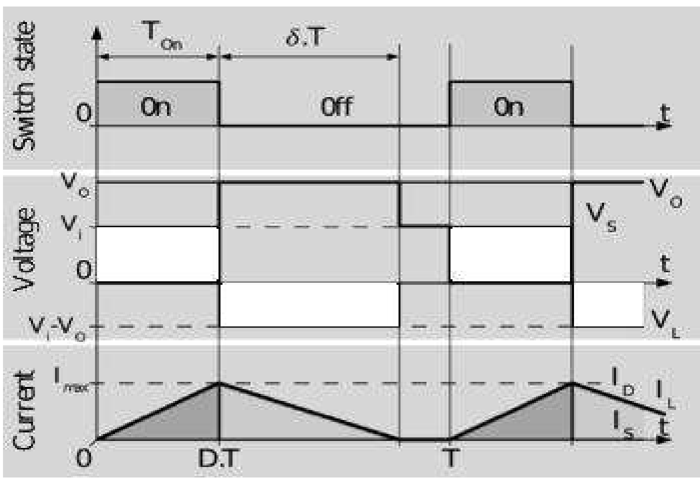


Fig 3 Waveforms of current and voltage operating in discontinuous mode.

If the ripple amplitude of the current is too high, the inductor may be completely discharged before the end of a whole commutation cycle. This commonly occurs under light loads. In this case, the current through the inductor falls to zero during part of the period (see waveforms in figure 4). Although slight, the difference has a strong effect on the output voltage equation. It can be calculated as follows:

As the inductor current at the beginning of the cycle is zero, its maximum value $I_{L_{Max}}$(at $t = DT$) is

$$I_{L_{Max}} = \frac{V_i DT}{L}$$

During the off-period, I_L falls to zero after δT :

$$I_{L_{Max}} + \frac{(V_i - V_o)\,\delta T}{L} = 0$$

Using the two previous equations, δ is:

$$\delta = \frac{V_i D}{V_o - V_i}$$

The load current I_o is equal to the average diode current (I_D). As can be seen on figure2.7,the diode current is equal to the inductor current during the off-state. Therefore the output current can be written as:

$$I_o = \bar{I_D} = \frac{I_{L_{max}}}{2}\delta$$

Replacing I_{Lmax} and δ by their respective expressions yields:

$$I_o = \frac{V_i DT}{2L} \cdot \frac{V_i D}{V_o - V_i} = \frac{V_i^2 D^2 T}{2L\,(V_o - V_i)}$$

Therefore, the output voltage gain can be written as follows:

$$\frac{V_o}{V_i} = 1 + \frac{V_i D^2 T}{2LI_o}$$

Compared to the expression of the output voltage for the continuous mode, this expression is much more complicated. Further more, in discontinuous operation, the output voltage gain not only depends on the duty cycle, but also on the inductor value, the input voltage, the switching frequency, and the output current. This circuit is used when a higher output voltage than input is required. While the transistor is ON Vx =Vin, and the OFF state the inductor current flows through the diode giving Vx =Vo. For this analysis it is assumed that the inductor current always remains flowing (continuous conduction).

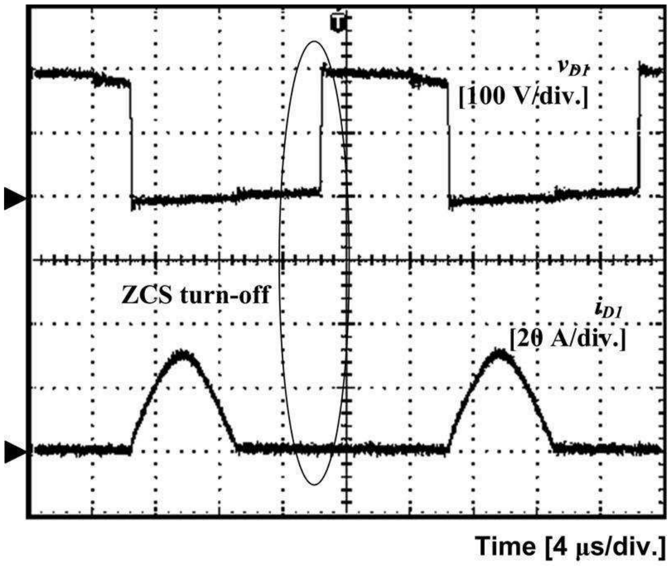
The average must be zero for the average current to remain in steady state this can be rearranged as

$$Vin\, t_{on} + (Vin - Vo)\, t_{off} = 0$$

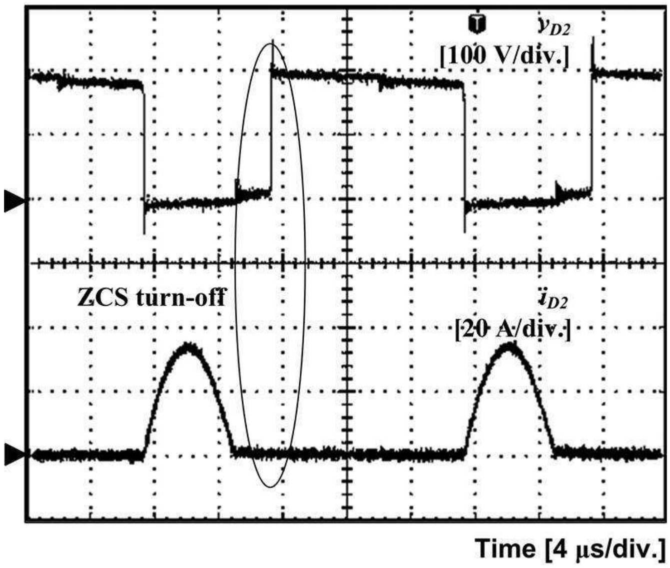
and for a lossless circuit the power balance ensures

$$\frac{Io}{Iin} = (1 - D)$$

Since the duty ratio "D" is between 0 and 1 the output voltage must always be higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the output voltage. A power inverter, or inverter, is an electronic device or circuitry that changes direct current (DC) to alternating current (AC). The input voltage, output voltage and frequency, and overall power handling, are dependent on the design of the specific device or circuitry.



(a)



(b)

Fig 4 Experimental waveforms of the ZCS turn-off of the output diodes.
(a) *vD*1 and *iD*1 . (b) *vD*2 and *iD*2 .

MATLAB DESCRIPTION

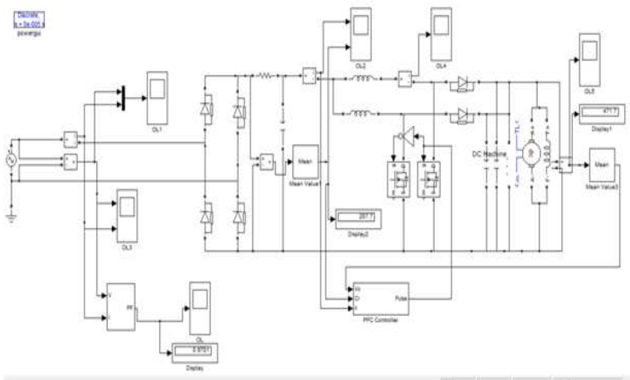


Fig 5 MATLAB Circuit

The MATLAB circuit diagram given below is to design single power AC to DC converter to produce high power factor and high efficiency output. Here the AC input form the supply is first rectified by using the rectifier circuit with the diode is in the bridge rectifier position the input AC supply is rectified now with the rectifier this AC supply voltage and current is show and determine by using the sensors.This rectified DC is having some power factor reduction it this should be now corrected by using the DC to DC converter with full efficiency by given simultaneously changing it mode from the continuous and discontinuous conduction modeThat should be called as the mixed conduction mode. The rectified DC supply is now calculating the mean and give to the PWM generator.

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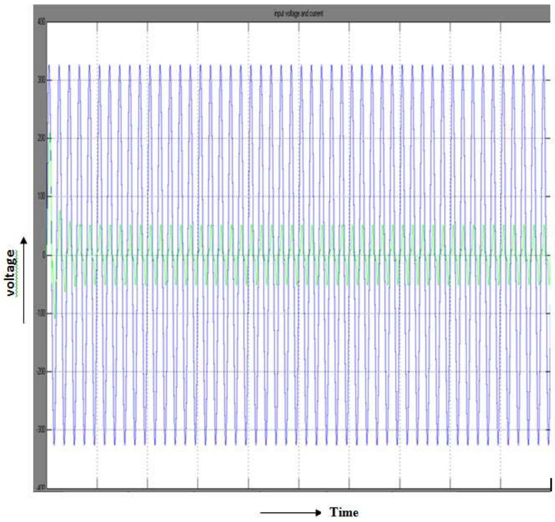

Fig 6 Input Voltage And Current

Then the dc positive voltage is given to the inductor improving the current in the circuit and that should be given to drain of the MOSFET and then connected to the freewheeling diode for giving gradual flow of current. And then the boosted higher output voltage is the output of the convertor.This likewise another boost convertor connected here and the should be controlled by a pulse width modulated signal from the generator depends on the dc supply from the power factor variation in the circuit. Hence the power factor corrected output voltage and current depend on the input ac voltage is drawn in the graph.

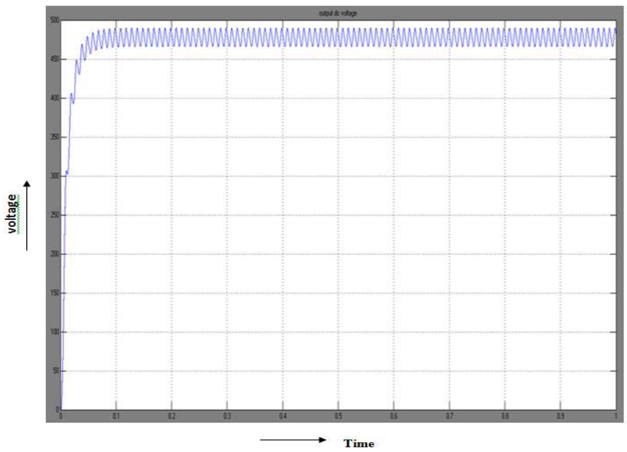

Fig 7 Output Dc Voltage

The input is not visible when internal generation of modulating signal (s) is selected. The input is the vector of modulating signals when internal generation of modulating signal is not selected. Connect this input to a single-phase sinusoidal signal when the block is used to control a single- or a two-arm bridge, or to a three-phase sinusoidal signal when the PWM Generator block is controlling one or two three-phase bridges.The output contains the two, four, six, or twelve pulse signals used to fire the self-commutated devices (MOSFETs, GTOs, or IGBTs) of single-phase, two-phase, or three- phase bridges or a combination of two three-phase bridges. These PWM for the interleaved boost converter and the inverter are to be produced by using the microcontroller for switching the MOSFET or other switching devices in the hardware.

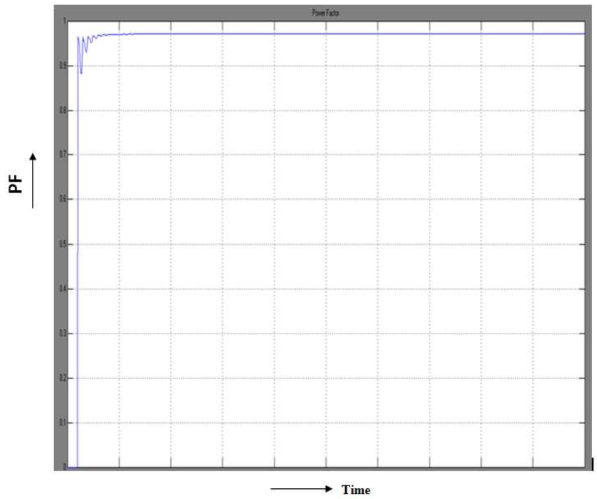

Fig 8 Power Factor

Time

4.CONCLUSION

This paper has proposed a single power-processing ac–dc converter with a high power factor based on zvzcs. Also, analysis, design, and experimental results for the proposed converter have been presented. The proposed converter combines the full-bridge diode rectifier and the series-resonant active-clamp dc–dc converter. The series-resonant active-clamp dc– dc converter is based on a flyback converter that employs the active-clamp at the transformer primary side and the voltage doubler at the transformer secondary side to reduce the switching losses and the voltage stress of the main switch suffered from the transformer leakage inductance. Also, the proposed converter provides a simple structure, a low cost, and low voltage stresses by the single power-conversion without a PFC circuit. Therefore, the proposed converter is suitable for low-power applications. The proposed converter has low line current harmonics to comply with the IEC 61000-3-2 Class D limits and the high power factor of 0.995 by using the proposed control algorithm for both PFC and power control. The proposed control algorithm can be used to the boost type PFC ac–dc converters since it is based on the control algorithm of the PFC boost converter in the continuous conduction mode. The proposed converter provides the high efficiency of 95.1% at the full load by the single power-processing, the turn-on ZVS mechanism of the switches by the active-clamp circuit, and the turn-off ZCS mechanism of the output diodes by the series resonance.

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