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Modified Ac-Dc Single-Stage Converters

Gerry Moschopoulos[†*], Yan Liu[*], and Sondeep Bassan[*]

[†*]Department of Electrical and Computer Engineering, University of Western Ontario, London, Ontario, Canada

ABSTRACT

Ac-dc power conversion can either be done with two separate converter stages or with a single converter stage. Two-stage ac-dc converters, however, can be costly and complex, while the performance of single-stage converters is compromised due to a reduced number of components. Several researchers have therefore proposed adding some sort of auxiliary circuit consisting of a second switch and some passive elements to single-stage converters to improve their performance. Although these modified single-stage converters may have two converters, they are not two-stage converters as they do not have two separate and independently controlled converters that are always operating to convert power from one form to another. In this paper, the operation of ac-dc single-stage converters is first reviewed and their strengths and weaknesses are noted. The operation of several modified single-stage converters, including one proposed by the authors, is then discussed, and the paper concludes by presenting experimental results that confirm the feasibility of the proposed converter.

Keywords: ac-dc converters, switch-mode converters, single-stage-converters, rectifiers

1. Introduction

Ac-dc converters with power factor correction (PFC) are typically placed in front of isolated dc-dc converters such as flyback or forward converters as part of a two-stage approach to ac-dc conversion, as shown in Fig. 1(a). The ac-dc converters tend to be boost converters that actively shape the input current so that it is sinusoidal and in compliance with regulatory agency standards such as EN61000-3-2. The current shaping is performed by having the boost converter switch turn on and off in an appropriate manner so that an input current waveform like the one shown in Fig. 1(b) can be obtained. It can be seen that this waveform is a discontinuous current waveform bounded by a sinusoidal envelope and is thus actually a sinusoidal waveform with high frequency harmonics that can be easily filtered out.

Two-stage ac-dc converters, however, can be costly and complex because there are two switch-mode converter stages present, each requiring a separate controller. This has led power electronics researchers to propose single-stage converters [1]-[11] that combine the front-end ac-dc PFC stage with the isolated dc-dc converter in a single stage. Although single-stage converters are popular, their performance can never be as good as that of conventional two-stage converters. This is due to fact that they are single converters and thus do not have a second

Manuscript received September 18, 2006; revised December 5, 2006
[†]Corresponding Author: gmoschopoulos@ece.uwo.ca
Tel: 519-661-2111 Ext. 88540, Fax: 519-850-2436
Department of Electrical and Computer Engineering

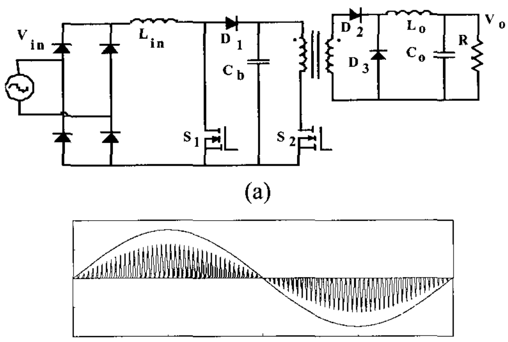


Fig. 1 (a) A conventional ac-dc two-stage converter.
(b) A typical discontinuous input current waveform.

independent converter that can be used to improve performance.

Several researchers have therefore proposed adding some sort of auxiliary circuit consisting of a second switch and some passive elements to single-stage converters to improve their performance. Although the auxiliary circuit is used as a second converter, these modified single-stage converters cannot be classified as two-stage converters because the auxiliary circuit may only be operating part of the time and/or it is not controlled by an independent controller but with the same controller as the main converter. Modified single-stage converters are not like conventional two-stage converters that have two separate and independently controlled converters that are always operating to convert power from one form to another. They can therefore be considered to be "one-and-a-half-stage" converters as they are neither pure single-stage converters nor pure two-stage converters.

One-and-a-half-stage (OHS) converters, however, are not nearly as well-known as single-stage converters or conventional two-stage converters and thus the main objective of this paper is to correct this oversight by reviewing the operation of several OHS converters. In this paper, the operation of ac-dc single-stage converters is first reviewed and their strengths and weaknesses are noted. The operation of several OHS converters, including one proposed by the authors, is then discussed. The paper concludes by presenting experimental results that confirm the feasibility of the proposed converter.

2. Single-Stage Converters

Single-stage converters can either be current-fed or voltage-fed, depending on whether there is a capacitor connected to the dc bus of the primary-side of the main power circuit transformer. Current-fed converters do not have this capacitor while voltage-fed converters do. The operation of ac-dc single-stage current-fed and voltage-fed converters will be explained in this section of the paper.

2.1 Current-fed converter

An ac-dc single-stage current-fed flyback converter is shown in Fig. 2; it has two basic modes of operation. When the switch is on, the rectified line voltage is impressed across the primary transformer winding and input current rises as energy is placed in the transformer. When the switch is off, there is no input current flow as the energy that was stored in the transformer is released to the output. The converter's operation can be considered to be analogous to that of a one-switch PWM boost converter because the boost converter has the same two key modes of operation - one mode where energy is placed in the boost inductor and input current rises, and another mode where energy is transferred to the load. As in a boost converter, the input current can be made to be bounded by a sinusoidal envelope so that a good input power factor is achieved.

In addition to a good input power factor, there is a direct link between input and output as energy from the input can be transferred directly to the output through the transformer, without passing through any intermediate stage that can result in losses. As a result, power from the input of the current-fed converter is processed only once instead of twice as it would be in a conventional ac-dc two-stage converter. The converter, however, has the following drawbacks that stem from the fact that it does not have a primary-side dc bulk capacitor:

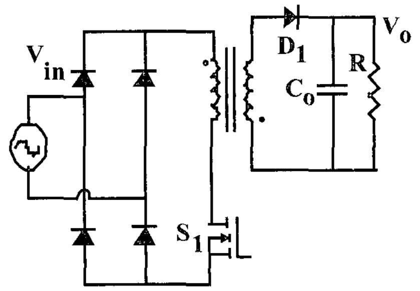


Fig. 2 An ac-dc single-stage current-fed converter.

(i) The converter is similar to a boost converter and, like a boost converter, the current fed to the output capacitor is a rectified sinusoidal waveform with a large low frequency 120 Hz component. This is so even though the main power transformer is a high-frequency transformer that does not handle a 120 Hz component; the 120 Hz component is reconstructed at the secondary transformer. As a result, the output current ripple of the current-fed converter is very large and this, in turn, results in a considerable output voltage ripple. Since there is only one capacitor that serves as an output filter, this capacitor must be very large to reduce the voltage ripple.

(ii) A hold-up time is typically specified for ac-dc power converters. Hold-up time is the time during which the converter can continue to maintain a regulated output dc voltage when the input ac voltage is unavailable. This requirement is typically met by having sufficiently large bulk capacitance at the dc bus to store energy. Since a current-fed converter does not have a dc bus capacitor, it will have a very low hold-up time.

The large output ripple and low hold-up time restrict the use of ac-dc single-stage current-fed converters to a limited number of applications where these limitations are not an issue.

2.2 Voltage-fed converter

Ac-dc single-stage voltage-fed converters are converters that have a primary-side dc bus capacitor and thus do not have the drawbacks that current-fed converters do. Fig. 3 shows an example of a simple single-stage forward converter in which both ac-dc and dc-dc power conversion are integrated in one converter. (Note that the demagnetizing winding is not shown in the figure.) The converter works as follows: When switch S_1 is on, energy stored in the primary-side dc bus capacitor C_b is transferred to the output and the current in input inductor L_{in} rises as the full rectified input voltage $V_{in,rec}$ is placed across it. When switch S_1 is off, no energy is transferred and the transformer demagnetizes. The current in L_{in} also starts flowing into capacitor C_b when S_1 is turned off, and continues to do so until either S_1 is turned on again or there is no more current left in the inductor. Since the input

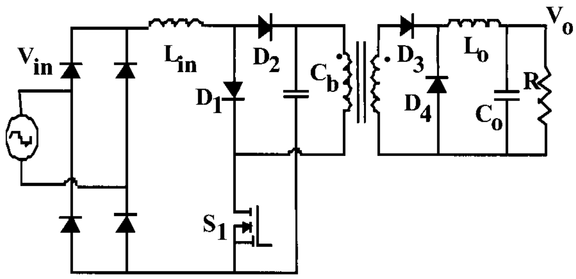


Fig. 3 An ac-dc single-stage, voltage-fed converter.

section of the converter is equivalent to a boost converter, the dc bus voltage V_b will always be greater than the rectified input voltage so that a negative voltage is impressed across L_{in} when S_1 is turned off. The converter is operated with a nearly fixed duty cycle over the entire input cycle just like a regular dc-dc converter so that the output current does not have a low frequency ripple. The input section is not controlled.

The following should be noted about the converter and about ac-dc single-stage voltage-fed converters in general:

(i) The converter should be designed so that the input current is fully discontinuous and a good input power factor can be achieved. As shown in Fig. 1(b), the current is bounded by a sinusoidal envelope so that it is in effect a sinusoidal waveform with high frequency components

(ii) The primary-side dc bus voltage in a single-stage is not regulated as it is in a conventional two-stage converter because there is no separate and independent ac-dc converter to control this voltage. What determines the dc bus voltage level is the energy equilibrium that exists at the dc bus capacitor when the converter is in steady-state operation - the energy pumped into the capacitor from the input section is equal to the energy that the capacitor provides to the output.

(iii) The relationship between dc bus voltage and load for various combinations of N, L_{in}, and L_o, in a single-stage converter has been reported in the power electronics literature (i.e. [1], [9]) and can be summarized as follows:

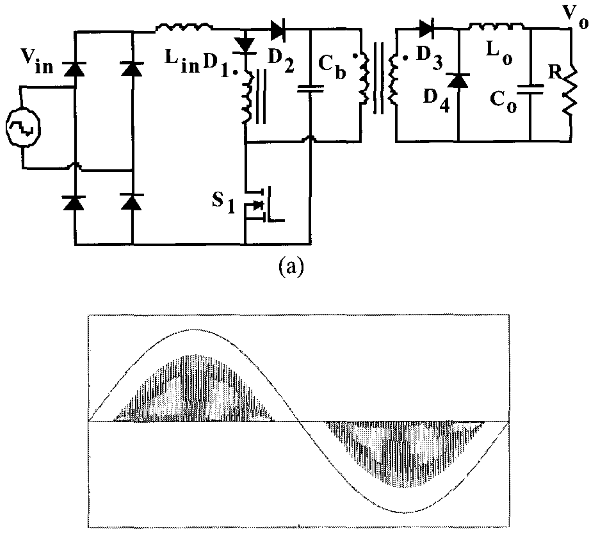
1) The dc bus voltage is independent of the load and is dependent only on the input voltage if both output current and input current are discontinuous. It is dependent on the ratio of L_{in}/L_o and on the

transformer turns ratio N.

2) It increases when the load is decreased if the input current is discontinuous and the output current is continuous.
3) It decreases as L_{in} is increased and the other component values are kept constant.
4) It decreases as L_o is decreased and the other component values are kept constant. This property is most apparent when the output current has a considerable ripple so that a change in L_O has a greater effect on this current.
5) It decreases as N is decreased and the other component values are kept constant.

(iv) The dc bus voltage may become excessive (i.e. > 800 V) under certain input line and output load conditions - particularly high line and light load - unless certain measures are taken. It is common practice to restrict this voltage to be less than 450 V dc to limit the voltage ratings of the converter components and the size of the dc bus capacitor. A technique that is commonly used to achieve this is to add an auxiliary transformer winding to the converter between the input inductor and the switch as is shown in Fig. 4(a). When the switch is turned on, a voltage is impressed across the winding so that the net voltage across the inductor is reduced. This reduces the energy that is placed in the inductor and, thus, the energy transferred to the dc bus capacitor so that the dc bus voltage is reduced. The converter is forced to operate with a larger duty cycle than it would if it did not have the auxiliary winding so that the end result is that an energy equilibrium that yields a lower dc bus voltage is established.

(v) The main drawback to implementing a single-stage converter with an auxiliary transformer winding is that the input current becomes distorted, as can be seen in Fig. 4(b). This is because there cannot be any input current flow when the input voltage is less than the voltage impressed across the auxiliary winding so that the input current waveform has "dead-band" regions where it must be zero. The width of these regions is dependent on the magnitude of the impressed voltage. If too large a voltage is impressed across an auxiliary winding to lower the dc bus voltage, the dead-band regions in the input current may become so wide that



(a)

(b)

Fig. 4 (a) An ac-dc single-stage, voltage-fed converter with an auxiliary transformer winding (b) A typical input current with deadbands at the zero-crossings.

the input current becomes too distorted to comply with regulatory agency standards on harmonic content.

(vi) It is a challenge to design an ac-dc single-stage voltage-fed converter so that it operates with a satisfactory input power factor, a dc bus voltage less than 450 V, and a low output current ripple (for forward converters) under a wide range of line and load conditions. For example, a low value of L_{in} may improve the power factor, but could cause V_b to exceed 450 Vdc when the converter is operating under light load conditions. Single-stage converters are thus best suited for applications where the operating conditions are restricted such as in applications where the input ac line voltage is limited to either a low range (85 - 132 Vrms) or a high range (176-265 Vrms). They are not as well suited for universal range applications (85-265 Vrms).

3. One-and-a-Half-Stage Converters

In this section of the paper, four one-and-a-half-stage (OHS) converters that are modified versions of standard current-fed and voltage-fed converters are examined. These include: (i) A parallel-connected OHS converter;

(ii) An OHS converter with a hold-up time extension circuit; (iii) An OHS converter with an auxiliary switch for power factor improvement; (iv) A higher power OHS forward converter with a bypass switch.

3.1 A parallel-connected OHS converter

The main drawbacks of a single-stage ac-dc current-fed converter such as the one shown in Fig. 2 are related to the fact that it does not have a primary-side dc bus bulk capacitor. As discussed in Section 2.1, the lack of such a capacitor means that the converter has poor hold-up time and a large output ripple. A modified current-fed single-stage converter that does have a primary-side dc bus capacitor and thus does not have these problems is the single-stage converter that was proposed in [12] and is shown in Fig. 5.

The converter consists of two flyback converters that are connected in parallel. Flyback converter I is a regular dc-dc flyback converter that is fed from dc bus capacitor C_b. Flyback converter II is a current-fed single-stage flyback converter that is fed directly from the output of the input diode bridge rectifier and operates as explained in Section 2.1. The overall parallel-connected converter operates as follows. When switch S_2 is turned on, the current through input inductor L_{in} rises, and energy is placed in transformer T_2. When the switch is turned off, T_2 is demagnetized and the current through L_{in} falls as energy from L_{in} is transferred to C_b. Switch S_2 operates in the same way as does the boost converter switch in a conventional two-stage converter with the only real difference being that S_2 in flyback converter II provides a

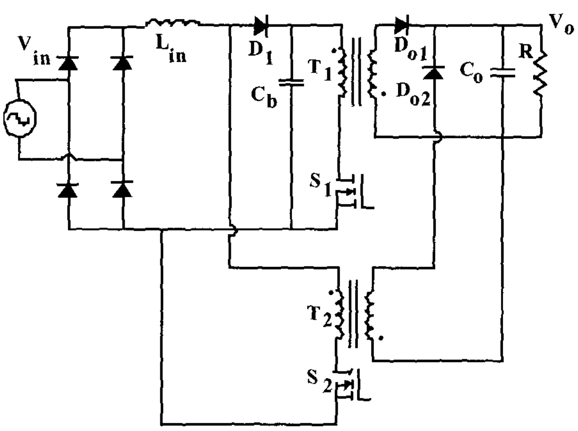


Fig. 5 A parallel-connected OHS converter.

means for energy to be directly transferred from the input to the output. S_2 is used to perform input power factor correction by shaping the input current so that it is sinusoidal.

Flyback converter I operates in the exact same way as a dc-dc flyback converter would in a conventional two-stage converter, but is controlled differently. Instead of operating with the same duty-cycle through the input ac line cycle as it would if it were the dc-dc converter in a conventional two-stage converter, flyback converter I is used to reduce the output ripple. The energy transferred from flyback converter II to the output is also low when the input voltage is low and high when the input voltage is high. In order to reduce the output ac ripple, flyback converter I is operated with the maximum duty-cycle when the input ac voltage is low so that it can transfer maximum energy to the output when flyback converter II cannot, and it is operated with the minimum duty-cycle (and may even not be operating at all) to minimize the energy that its transfers to the output when the input ac voltage is high and flyback converter II transfers maximum energy to the output. Output ripple is reduced if flyback converter I is operated in this manner as a less varied, more consistent transfer of energy from primary to secondary output is ensured.

The parallel-connected converter is a mixed single-stage / two-stage converter as roughly half the power can be delivered from the input to the output directly through flyback converter II while the remaining half is delivered through flyback converter I by a two-stage process. It can therefore be considered to be an OHS converter even though it requires two individual and separate converters with two separate control circuits. Since half the power is delivered through a single-stage where it is only processed once, this converter is more efficient than a conventional two-stage converter.

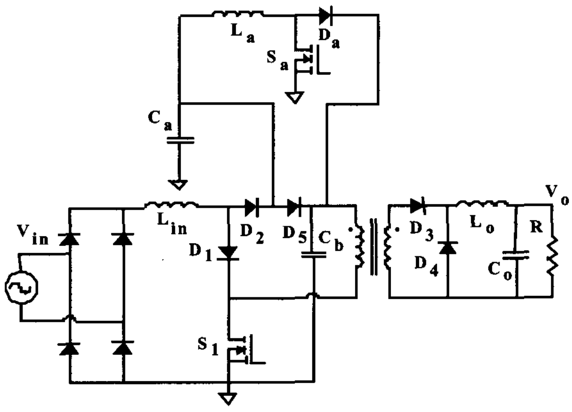
3.2 An OHS converter with a hold-up time extension circuit

The fact that the primary-side dc bus voltage of an ac-dc single-stage converter is dependent on converter operating conditions has an effect on the hold-up time that the converter can operate with its specified output voltage after the ac line becomes absent. Once the primary-side dc bus voltage drops below a certain level, $V_{b,min}$, the converter becomes unregulated as it will not be able to deliver its specified output voltage even though it is operating with its maximum possible duty-cycle. A variable dc bus voltage means that it can swing considerably from a low value to a high value depending on the operating conditions. This forces the use of a lot of large, high-voltage capacitors at the dc bus so that hold-up requirements can be satisfied regardless of whether the dc bus is low or high, which, in turn, may result in an increase in capacitor size and converter size.

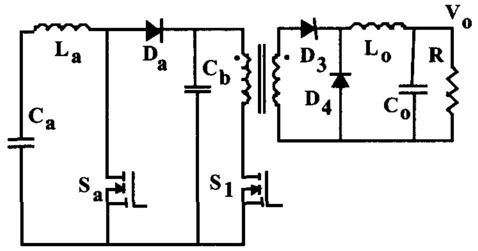
The amount of dc bus capacitance needed for a given, required hold-up time in an ac-dc single-stage voltage-fed converter can be reduced if a dc-dc boost converter is added to the converter as a hold-up time extension circuit, as is shown in Fig. 6. This converter is connected at the input of the dc-dc part of the converter and is only active when the ac line is absent; otherwise, it is turned off and shorted out of the power delivery path. The total dc bus capacitance is split in two to provide energy at the input of the hold-up time extension converter. The larger part of this capacitance is connected at the input of the hold-up time extension circuit and the smaller part is connected at the output of the circuit, at the input of the dc-dc part of the single-stage converter.

The way the circuit works is as follows: When the ac line suddenly becomes absent, the voltage across both C_a and C_b drops. When this voltage drops below $V_{b,min}$, the dc-dc boost converter hold-up extension circuit capacitor is activated with C_a being the input dc source and C_b being the output capacitor, as shown in Fig. 6(b). While the voltage across C_a is dropping, the circuit maintains the voltage across C_b at around $V_{b,min}$ so that the specified output voltage can be delivered to the load. If the ac line is absent for a long enough time, eventually what happens is that the voltage across C_a drops to such a low level that the hold-up time extension circuit cannot deliver $V_{b,min}$ to C_b and thus the output load voltage drops below its specified level.

Since the hold-up extension circuit does not interfere with the operation of the converter as it is activated only when it is needed, the converter can be considered to be an OHS converter. Moreover, the circuit's components have much smaller current ratings than those of the main converter as the circuit is in operation for a very short amount of time and only when the ac line is absent. The size and weight of the circuit can be reduced if an integrated magnetics approach is used to eliminate the need for a separate hold-up extension circuit inductor, L_a. Details on how this can be done are presented in [13].



(a)



(b)

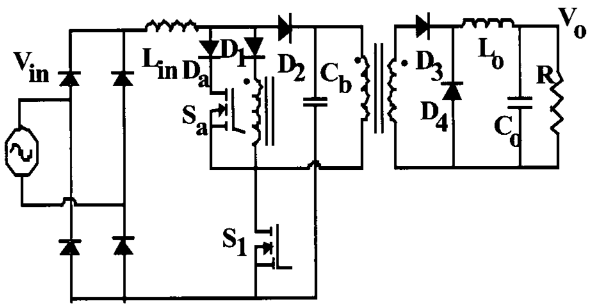
Fig. 6 (a) An OHS converter with a hold-up time extension circuit. (b) Equivalent circuit when the ac line is down.

3.3 An OHS converter with an auxiliary switch for power factor improvement

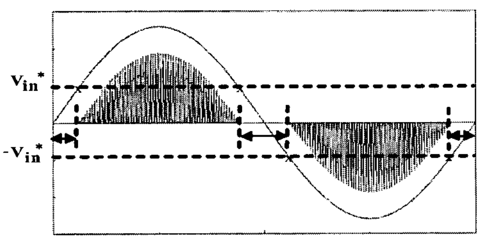
In any ac-dc single-stage voltage-fed converter implemented with an auxiliary transformer winding to reduce the primary-side dc bus voltage, a compromise must be made between dc bus voltage reduction and input power factor. Increasing the number of turns of the auxiliary winding will result in a lower primary-side dc bus voltage but also a lower input power factor as the length of time that input current cannot flow is increased. In order to achieve a reduced dc bus voltage, but with a higher input power factor, an auxiliary switch can be added to the converter as was proposed in [14] and shown in Fig. 7(a).

The auxiliary switch S_a is never activated during an input ac line cycle unless the instantaneous input voltage is around the zero crossings. It is only when the input voltage is below a certain, predetermined level, V_{in}*, as shown in Fig. 7(b), that switch S_a is turned on to bypass the auxiliary transformer winding. Doing so makes the circuit the same as the one shown in Fig. 3 so that input current can flow in the converter when it would not be able to otherwise as the voltage across the auxiliary winding would have made the input diode bridge rectifier diodes reverse-biased. Once S_a is on, it is not turned off until the input ac voltage exceeds V_{in}*. S_a then remains off until the input ac voltage drops below V_{in}* sometime later in the ac cycle. Other than the time when the ac line voltage is around its zero crossings, the operation of the converter is almost exactly the same as that described in Section 2.2 for the voltage-fed converter in Fig. 3.

The input power factor is improved because the deadband region of the input current waveform, as shown in Fig. 7(b), is reduced and the waveform becomes more like the waveform shown in Fig. 1(b). The operation of the auxiliary switch has little effect on the dc bus voltage as it operates when the ac input is at its lowest and for a short period of time. The converter can be considered to be an OHS converter because S_a does not process power continuously, but only during the zero-crossings of the ac voltage waveform.



(a)



(b)

Fig. 7 (a) An OHS Converter with an auxiliary switch for power factor improvement. (b) Input waveforms without the auxiliary switch.

3.4 A higher power OHS forward converter with a bypass switch

It is more challenging to implement a higher power ac-dc single-stage voltage-fed two-switch forward converter such as the one shown in Fig. 8 than it is to implement an ac-dc single-stage voltage-fed single-switch flyback or forward converter. There has therefore been much less research published in the literature about two-switch, single-stage forward converters than on single-switch, single-stage forward converters. The challenge is due to the wider range of load variation and it is this wide variation that makes it difficult to achieve the objectives of satisfactory power factor, dc bus voltage less than 450 V, and low output current ripple. For example, a particular value of L_{in} that is satisfactory in a low power single-switch forward converter operating with a discontinuous input current may be inappropriate for a higher power converter. This is because operation with a heavier load could make the input current partially continuous and distorted and so that it would not satisfy the required regulatory agency standards. Reducing L_{in} in this case would improve the power factor, but would cause V_b to exceed 450 Vdc when the converter is operating under light load conditions.

Some other mechanism is therefore needed to significantly reduce the dc bus voltage in an ac-dc single-stage voltage-fed two-stage forward converter without compromising input power factor. One way of doing so is shown in Fig. 9(a) where it can be seen that

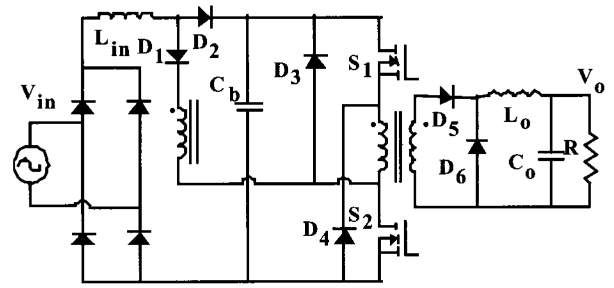


Fig. 8 An ac-dc single-stage voltage-fed two-switch forward converter.

another switch has been added to the converter. The gating signal of the switch can be derived from the same controller as that for the other two converter switches so that a second independent controller is not needed. The auxiliary switch allows C_b to discharge without simultaneously storing energy in L_{in}. This allows the energy equilibrium at C_b to be changed so that energy can be pumped out of C_b more often than it is pumped in, resulting in a reduction of the dc bus voltage V_b. The converter in Fig. 9(b) is a variation of the one in Fig. 9(a) except that the auxiliary transformer winding is a tapped winding.

The converter in Fig. 9(a) works as follows: Switches S_1 and S_2 can be on as shown in Fig. 10(a), which discharges C_b and places a positive voltage across L_{in} that makes the inductor current rise, or switches S_1 and S_3 can be on as shown in Fig. 10(b), which only discharges C_b. Regardless of what switches are on, when they are turned off, any current that was flowing through the transformer primary forces diodes D_3 and D_4 to conduct, as shown in Fig. 10(c), and a negative voltage appears across the primary transformer to demagnetize the transformer. Any current flowing through L_{in} is transferred into C_b.

Fig. 11 shows some typical converter waveforms when S_2 and S_3 are turned on in alternate switching cycles. It can be seen that the output current waveform I_o looks like that

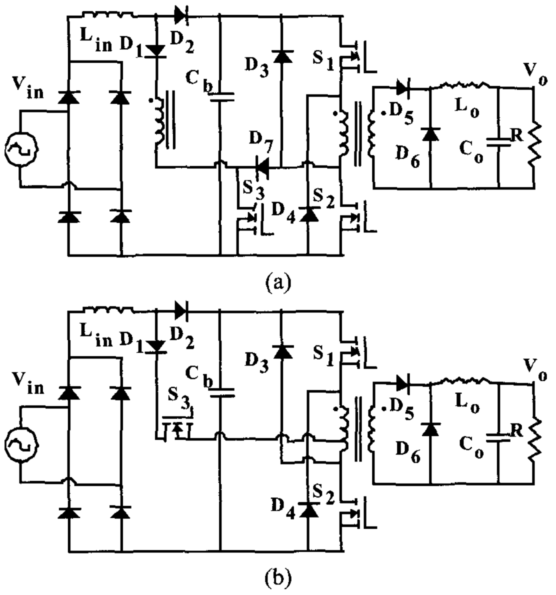


Fig. 9 A higher power OHS forward converter with a bypass switch (a) Implementation I (b) Implementation II.

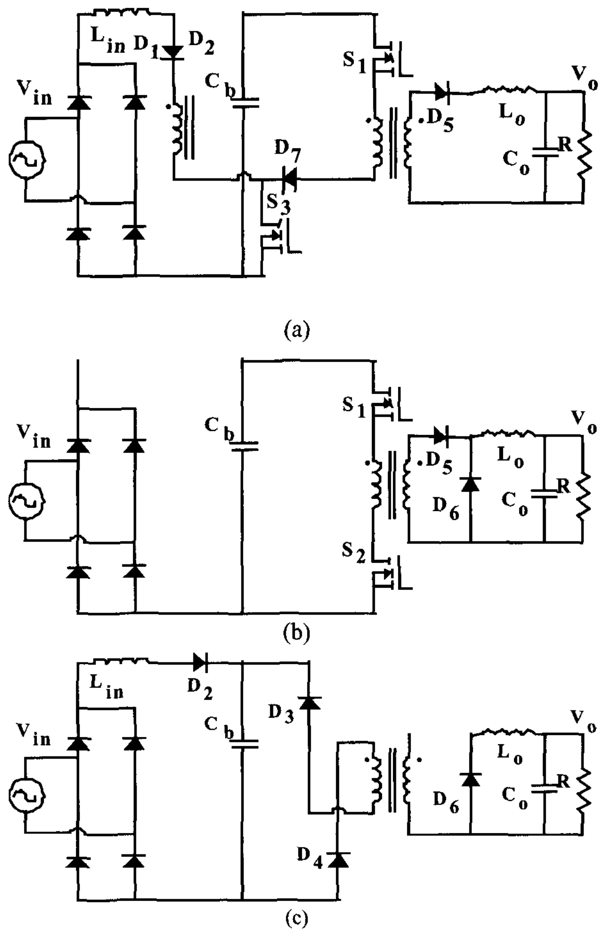


Fig. 10 Operation modes of two-switch, ac-dc PWM forward converter operating with an auxiliary bypass switch.

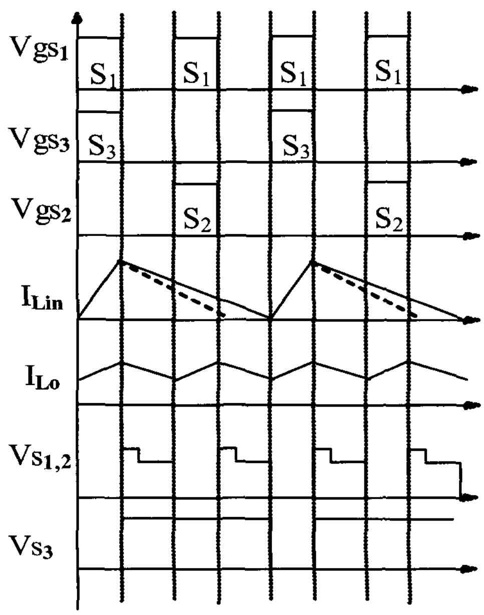


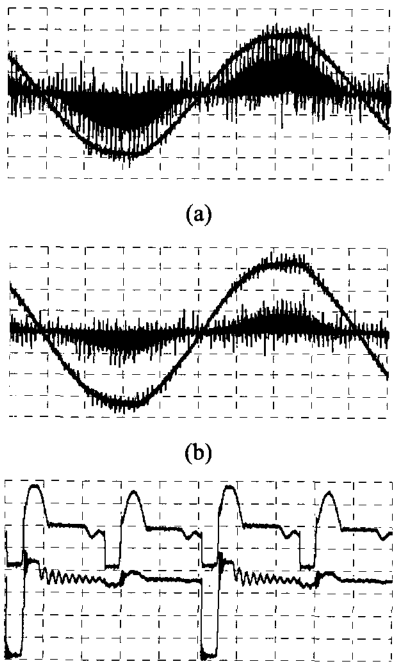
Fig. 11 Converter gating signals and current waveforms.

of a standard forward converter, while the input current is discontinuous and can fall to zero sometime before S_2 is turned on (as indicated by the solid and dotted lines). The amount of dc bus voltage reduction that can occur by implementing the auxiliary switch in the converter is dependent on the switching frequency of the switch with respect to that of the other bottom switch. A greater switching frequency will result in a greater reduction in dc bus voltage because there will be more opportunity for the dc bus capacitor C_b to discharge without energy being simultaneously stored in the input inductor. If S_3 is turned on too often, however, then V_b will become less than the input peak voltage and this will lead to significant distortion in the input current.

4. Experimental Results

A simple, experimental prototype converter was built as a "proof-of-concept" to confirm the feasibility of the higher power OHS forward Converter with a bypass switch. The forward converter topology shown in Fig. 4(a) was implemented. A 12 Vdc, 200 W, 100 kHz converter was built with input inductor L_{in} = 106 μH, output inductor L_o = 9 μH, transformer turns ratio N = 5, and auxiliary winding turns ratio N_x = 5. The S_3-S_2 switching frequency ratio of 1:1 was used (turning S_3 on 1 time for every 1 time that S_2 was turned on). The topology in Fig. 9(a) was chosen for simplicity. The converter component values were chosen so that the converter would meet EN61000-3-2 class D standards for electrical equipment (which apply when a converter is operating with 75 - 600W power and measured when V_{in} = 100 Vrms and 230 Vrms) and not have its dc bus voltage exceed the standard value of 450 Vdc. This was done based on computer analysis similar to that described in [9] and the reader is referred to that paper for details.

Fig. 12 shows experimental waveforms. Figs. 12(a) and (b) show typical input voltage and current waveforms when V_{in}= 100V and 230V. It can be seen that the converter can operate with a discontinuous input current and a good input power factor. Fig. 12(c) shows switch voltage waveforms; the voltage of S_2 is the same as that of S_1. Fig. 13 shows the experimental input power factor (PF), the efficiency η, and the dc bus voltage V_b versus output



(a)

(b)

(c)

Fig. 12 Typical experimental waveforms P_o = 100W : (a) Input voltage and current with V_{in}=100Vrms, scale: V: 50V.div, I: 2A/div, t = 2ms/div. (b) Input voltage and current with V_{in} = 230Vrms, scale: V: 100V/div, I: 2A/div, t = 2ms/div. (c) Switch voltage waveforms S_1 and S_2 (top) and S_3 (bottom) V_{in}=230V rms, scale: V: 100V/div, t = 4 μs/div.

load for input voltages V_{in}= 100V and 230V. It can be seen that the input power factor is generally about 0.8-0.85, the efficiency is generally about 75% and the dc bus voltage can be kept below 450 Vdc. Fig. 14 compares the worst-case input current harmonics, which occur at P_o = 200 W when V_{in} = 100 Vrms and P_o = 200 W when V_{in} = 230 Vrms, with the EN61000-3-2 class D standards for electrical equipment. It can be seen that EN61000-3-2 class D standards for electrical equipment are met.

The wider variation in load range has limited research into two-switch single-stage forward converters. The most notable two-switch single-stage forward converters were the ones presented in [10] and [11] that were operated with a universal input voltage range. The dc bus voltage of the converter in [10] is considerably higher than the accepted maximum of 450 Vdc and thus physically larger capacitors are needed for the primary-side dc bus capacitor. The experimental results presented here are more

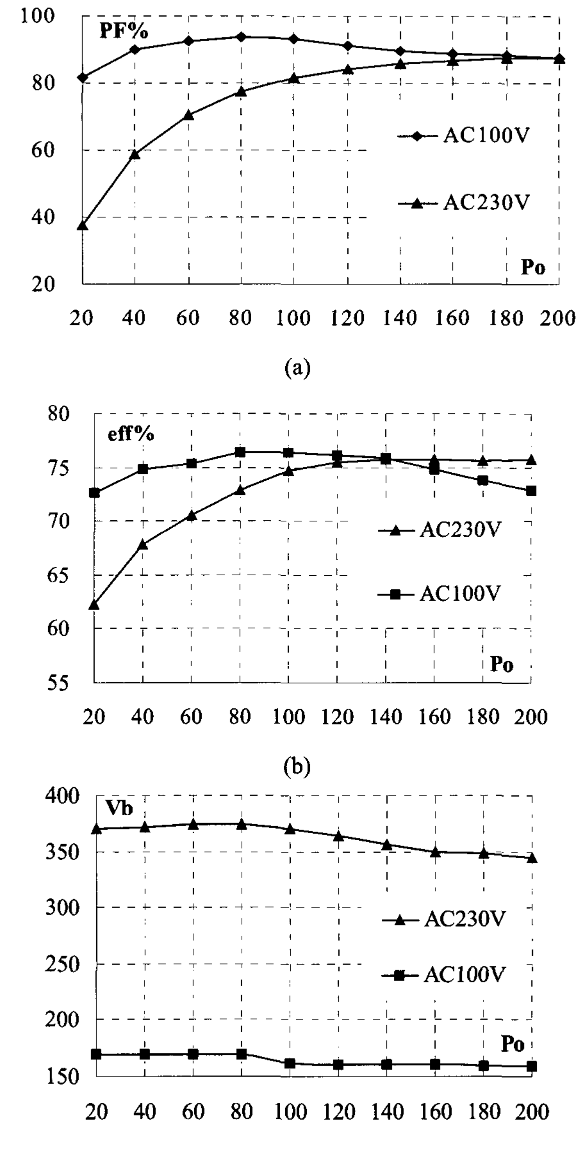


Fig. 13 Experimental performance characteristics: (a) Input power factor vs. output power. (b) Efficiency vs. output power. (c) Dc bus voltage vs. output power.

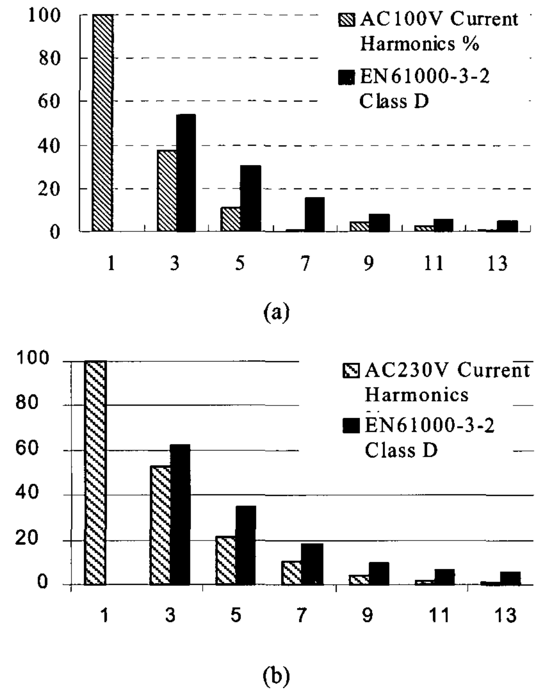


Fig. 14 Input harmonic content (a) Input voltage V_{in} = 100 Vrms, output power P_o = 200W. (b) Input voltage V_{in} = 230Vrms, output power P_o = 75W.

comparable to those reported for the converter in [11], but the load range for the converter in [11] is limited to 130 W as the converter cannot operate under a larger load without compromising performance.

5. Conclusion

One-and-a-half-stage (OHS) converters are modified single-stage converters that are neither pure single-stage converters nor pure two-stage converters. These converters do not have some of the weaknesses of single-stage converters, which include reduced power factor and excessive dc bus voltage. They can be simpler, less expensive, and/or smaller than two-stage converters because they do not have two separate and independently controlled converters that are always operating to convert power from one form to another. OHS converters, however, are not well-known and the main objective of this paper has been to examine the operation of several converters of this type. In this paper, the operation of ac-dc single-stage converters was reviewed, and the operation of several OHS converters, including one proposed by the authors, was then discussed. Experimental results that confirmed the feasibility of the proposed converter were presented.

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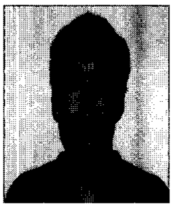
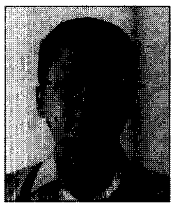


Gerry Moschopoulos received the Bachelor of Engineering, Master's of Applied Science and Ph.D degrees from Concordia University in Montreal, Quebec, Canada in 1989, 1992, and 1997 respectively. From 1996 to 1998, he was a design engineer in the Advanced Power Systems division of Nortel Networks in Lachine, Quebec, Canada, working on developing power supplies and systems for telecom applications. From 1998 to 2000, he was a research engineer at Concordia University. Since 2000, he has been with the Department of Electrical and Computer Engineering at the University of Western Ontario in London, Ontario, Canada, where he is currently an associate professor.



Yan Liu received the Bachelor of Engineering from Shandong University in Jinan, Shandong, China in 1991, Master's of Engineering and Science from University of Western Ontario in London, Ontario, Canada. From 1991 to 2000, he was an I&C engineer in Shandong Electrical Power Co. From 2003 to 2005, he worked for GE as field engineer. Since 2006, he has been an electrical design engineer in Lex Engineering Ltd. in Richmond, BC, Canada.

Sondeep K. Bassan received the Bachelor of Engineering, from Punjab Technical University in Jalandhar, Punjab, India in 1999 and Master's of Engineering degree from Punjab University in Chandigarh, Punjab, India in 2003. From 2002 to 2003 she was a lecturer in Ludhiana College of Engineering and Technology, Punjab, India. She is currently a Ph.D. student in the Department of Electrical and Computer Engineering at the University of Western Ontario in London, Ontario, Canada.