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DESIGN OF A NEW AC–DC SINGLE-STAGE FULL-BRIDGE PWM CONVERTER WITH TWO CONTROLLERS

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ABSTRACT

Single-phase power factor correction (PFC) ac–dc converters are widely used in the industry for ac–dc power conversion from single phase ac-mains to an isolated output dc voltage. Typically, for high-power applications, such converters use an ac–dc boost input converter followed by a dc–dc full-bridge converter. A new ac–dc single-stage high-power universal PFC ac input full-bridge, pulse-width modulated converter is proposed. The converter can operate with an excellent input power factor, continuous input and output currents, and a non excessive intermediate dc bus voltage and has reduced number of semiconductor devices thus presenting a cost-effective novel solution for such applications.

Index Terms—AC–DC power conversion, bridgeless power factor correction (PFC) converter, full-bridge onverters, pulse-width modulated (PWM), single-stage converters.

1. INTRODUCTION

The ac–dc power converters are typically implementedwith two converter stages. The first stage is an ac–dc frontend boost converter stage that converts the input ac voltage into an intermediate dc bus voltage and that also performs input power factor correction (PFC). This stage is followed by a second stage, which is a dc–dc converter that converts the dc bus voltage into the required dc output voltage. Converters that integrate the functions of PFC and isolated dc–dc conversion in a single power converter have been proposed to reduce the cost, size, and complexity associated with operating two separate switch-mode converters in conventional two-stageac–dc converters.

Single-stage ac–dc converters are popular for low-power (<250 W) ac–dc flyback and forward converters and are widely used in industry. Single-stage full-bridge converters for higher power applications (>500 W), however, are not as popular, and research on these converters has been challenging due to the larger variation in output load. It is more difficult for single-stage converters to perform PFC and dc/dc conversion simultaneously for wide load variations than it is for narrower load variations, which is the case for low-power applications.

Single stage ac–dc full bridge converters can either be current fed or voltage fed . Single-stage current fed ac–dc full-bridge converters , which have an input boost inductor connected to the input of the full-bridge section, have a large 120 Hz output ripple component that restricts their use to a limited number of applications. Voltage fed single-stage converters, which have a large energy-storage capacitor connected across the input of the full-bridge section, do not have this problem and thus can be used in many more applications.

Two-stage ac–dc converters are implemented with two controllers as each converter stage has a controller that is dedicated to regulating its output. This is rarely the case with single stage converters, which are typically implemented with just a single controller to regulate the output voltage, in order to reduce cost, size, and complexity. As a result, there is no dedicated controller that is available to regulate the dc bus capacitor voltage that is on the primary side of the main power transformer in the converter and that is the input of the dc–dc section of the converter.

The lack of such a such controller in single-stage converters means that

1) the primary-side dc bus voltage can vary significantly with vary line and load conditions and can be become excessive (>800–900 V) under high input line/light output load conditions; and

2) there is no controller that is available to shape the input current. It is fact that there is no second controller at the input section that is the cause of most of the drawbacks of previously proposed single-stage converters, including the following:

- Some previously proposed single-stage converter are resonant converters that use variable switching frequency control to prevent the dc bus capacitor voltage from becoming excessive. The use of variable switching frequency control makes it difficult to optimize the design of these converters in terms of the tuning of the resonant tank components and the size of the magnetic componentsas they must be able to operate over a wide range of switching frequency.

- Various methods have been proposed to reduce the dc bus capacitor voltage in fixed-frequency pulse-width modulated (PWM) single-stage converters operating with only one controller. Since the dc bus capacitor voltage is not regulated, it is affected by the energy equilibrium that must exist between the energy transferred to the dc bus capacitor from the input and the energy that is transferred from the capacitor to the converter output—these two energies must be the same by the end of any line period for steady-state converter operation. Each dc bus voltage reduction method tries to affect this dc bus energy equilibrium in some way, but each method has a significant drawback that limits its effectiveness.

- Since one-controller single stage converters have no controller to actively shape the input current, simultaneous input PFC and dc/dc conversion can only be performed by keeping the converter duty cycle fixed over the entire input line cycle. PFC in this case can only be ensured if the input inductor is designed to be sufficiently small so that the input current is discontinuous for all converter operating conditions and naturally bounded by a sinusoidal envelope. Such small input inductance values, however, restrict the amount of load that the converter can operate with as the input current peaks are extremely high at very high loads and low ac line input. As a result, most single-stage PWM converters have a maximum load of less than 1 kW.

- Several one-controller single stage converters must operate with non-standard control techniques in order to be able to perform input PFC and dc/dc conversion simultaneously, but these techniques may be extremely sophisticated for many power electronics engineers. For example, the converters proposed in cannot be operated with conventional phase-shift PWM and, instead, must operate with PWM techniques that are unique to the converters.

In addition to the drawbacks associated with the lack of a second controller to regulate the dc bus capacitor voltage and to actively shape the input current, many single-stage converters have drawbacks associated with increased conduction losses. Single-stage converters that use auxiliary windings taken from the main power transformer as “magnetic switches”, and single-stage full-bridge converters that use both bottom switches of the full-bridge to conduct current from the input section need additional blocking diodes to be placed in series with the input inductor(s) to prevent reverse inductor current from flowing, which would upset converter operation.

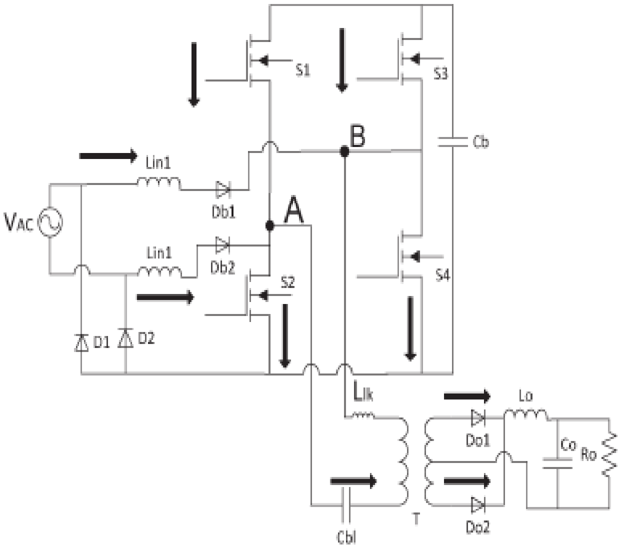

Fig. 1.Proposed single stage ac/dc converter.

The use of such blocking diodes increases conduction losses, as current from the input source must flow through three diodes (the two diodes in the input diode rectifier bridge plus a blocking diode) instead of two. This problem can be avoided by using a bridgeless diode rectifier arrangement in the input section, but very few single-stage voltage-fed converters can be implemented with a bridgeless input section.

A new voltage-fed PWM ac–dc single-stage full-bridge converter that has none of the aforementioned drawbacks is proposed in the paper. The proposed converter, shown in Fig. 1, can operate with excellent input power factor, universal input line, continuous input and output current, equal sharing of the input current in the full-bridge, a dc bus voltage that can be kept below the standard recognized limit of 450 V, and with standard and widely used control methods. Moreover, it can be implemented with a bridgeless input to help reduce conduction losses, particularly for low input line operation.

The main reason for these features is that it can be implemented with an input section controller so that the converter works with two controllers—one to regulate the output voltage and one for the input section of the converter, to regulate the dc bus capacitor (*C*bin Fig. 1) voltage and actively shape the input current. Although the addition of a second controller increases the cost, size, and complexity of the single-stage converter, they are still less than those of a conventional two stage converter.

2. PROPOSED CONVERTER

The proposed ac–dc single-stagefull-bridge converter combines an input section that consists of input inductors *L*in1 and *L*in2 and rectifying diodes *D*1 and *D*2 with a dc–dc section that is a standard full-bridge converter.Components *D*1, *D*2, *L*in1, and *L*in2 make up a bridgelessinput, which is based on the bridgeless converter presented. Blocking diodes *D*b1 and *D*b2 are included toprevent any dc circulating current. A dc blocking capacitor,*C*bl, is provided in series with the transformer primary. Thepositive directions of key currents and voltages to be used forthe analysis of the converter's modes of operation are shown inFig. 1 for clarification.

The following should be noted about the proposed topology:

- In most commonly known single stage converters, the input line current flows through four semiconductor devices two diodes and two switches or three diodes and either a top full-bridge switch or a bottom one. In the proposed topology, the current flows through one less diode.

- Although there are some PFC boost converters that claim to be bridgeless (i.e., [39]–[45]), most bridgeless converters are impractical because they have significantly more common-mode noise than the conventional PFC boost rectifier and thus require additional input filtering that offsets any advantage that they may have.

Of the proposed converter's two independent controllers, one is used to regulate the voltage across primary-side dc bus capacitor *C*bby sending appropriate gating signals to *S*2 and *S*4. The gating signals of *S*1 and *S*3 are the complimentary signals of *S*2 and *S*4, respectively. The other controller is used to regulate the output voltage by setting an appropriate phase shift between the gating signals of *S*2 and *S*4. Since the two controllers are independent, a standard controller IC such as the UC3854 or UCC28070 [50], [51] can be used for PFC and to control the dc bus voltage, and another standard controller IC can be used for realizing the phase-shift control between the two legs of the bridge.

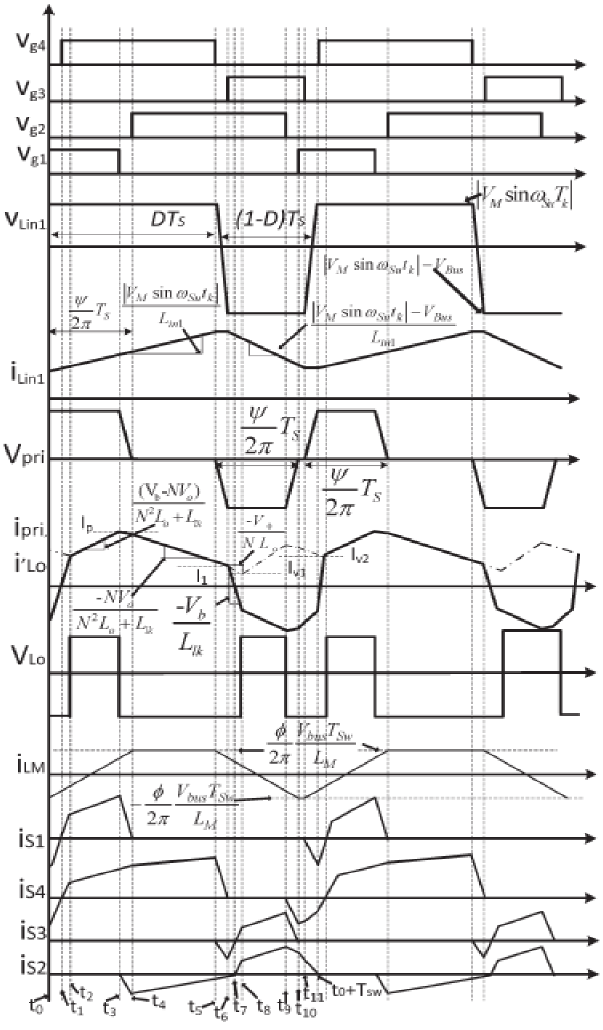

Fig. 2.Ideal operating waveforms of proposed converter.

The proposed converter has the following attractive features.

1) It combines the best features of a two-stage converter and a single-stage converter. It has two independent controllers that allow it to operate with a continuous input line current and a regulated dc bus voltage, like a two stage converter, but with fewer components, like a single stage converter.

2) The proposed converter can be implemented with standard controller ICs that are well-known to practicing power electronics engineers who are familiar with the design and implementation of the conventional two-stage boost/full-bridge topology.

3) The proposed converter has fewer semiconductor devices in the input current conduction path than most other single-stage converters [25]–[38], which reduces conduction loss.

4) By turning on the upper MOSFETs, *S*1 or *S*3, after the corresponding bottom MOSFETs, *S*2 or *S*4, are turned off with proper dead time, current from the input section can be made to flow through a MOSFET instead of its body diode. This can reduce the conduction losses of the input section even further, although there may be some body-diode switching losses which can be reduced by using MOSFETs with fast diodes like the IRFPS40N50L
MOSFET from international rectifier.

5) Since the input current is continuous, the peak current stress of the converter components is much lower than that found in almost all other single-stage converters , which must operate with discontinuous input currents. The proposed converter therefore also has fewer turn-off losses and can be implemented with a smaller input EMI filter than other single stage converters.

6) Since the output section can be operated with standard phase-shift PWM, the output diodes can be replaced with synchronous rectifier MOSFETs for high output current applications. This is something that is very difficult to do with converters that operate with non-standard control methods.

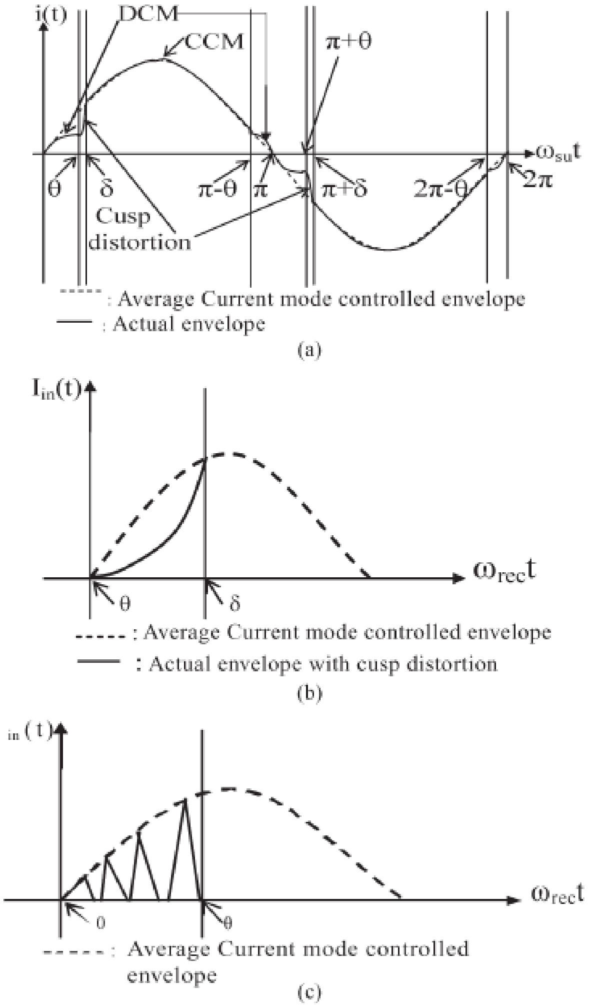

Fig. 3. (a) Input current envelope with duty ratio clamp. (b) Expanded inputcurrent envelope with cusp distortion. (c) Expanded waveform with discontinuous current at the zero crossing.

3. CONCLUSION

A new ac–dc single-stage full-bridge converter is proposed in this paper. The converter combines the best features of two stage and single-stage converters. Its performance approaches that of two-stage converters, while its cost approaches that of single-stage converters. The converter is controlled using two controllers—one is used to actively control input power factor and the intermediate dc bus voltage, the other is used to control output voltage. In this paper, the new converter was introduced and its operation and features were explained.

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