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INVESTIGATION ON THREE LEVEL ISOLATED PFC CONVERTER

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Abstract— For low-cost isolated ac/dc power converters adopting high-voltage dc-link, research efforts focus on single-stage multilevel topologies. This project proposes a new single-stage three-level isolated ac/dc PFC converter for high dc-link voltage low-power applications, achieved through an effective integration of ac/dc and dc/dc stages, where all of the switches are shared between two operations. With the proposed converter and switching scheme, input current shaping and output voltage regulation can be achieved simultaneously without introducing additional switches or switching actions. In addition, the middle two switches are turned on under zero current in discontinuous conduction mode operation, and the upper and bottom switches are turned on under zero voltage. Due to the flexible dc-link voltage structure, high power factor can be achieved at high line voltage.A500 W/48Vprototype is designed to serve as the proof of concept, which exhibits 90.8% peak efficiency at low input line voltage. With this proposed converter, the input current shaping and output voltage regulation can be achieved with the help of microcontroller based soft switching technique and it does not require any additional switches. Through this soft switching technique, the inverter switches are turned on under zero current and zero voltage in discontinuous conduction mode operation. Due to the flexible dc-link voltage, high power factor can be achieved with regulated dc output. A 300W/110V prototype is designed and developed for the proof of concept, which shows the power factor is in the range of 0.96 to 0.99.

1. INTRODUCTION

IN compliance with IEC 1000-3-2, ac/dc power converters are required to operate with high power factor (PF) and low total harmonic distortion (THD) for improved grid quality and full capacity utilization of the transmission lines. Passive PF correction (PFC) circuits consist of inductive and capacitive filters followed by a diode bridge provide the simplest way of achieving high PF with high efficiency; however, they require low line frequency filters which are bulky and heavy. In order to operate at high frequency and reduce the size of the circuit, high frequency two-stage active PFC converters have been proposed [1]–[4]. In this architecture, a front-end ac/dc PFC converter is operated with a switching frequency in the order of tenths to several hundred kHz for converters with Si semiconductor devices, and from several hundreds of kHz to tenths of MHz with wide-band gap devices, to shape the input current close to sinusoidal waveform in phase with the grid voltage [4]. The second stage dc/dc converter provides the galvanic isolation and output voltage regulation. The controllers of the two stages are completely independent.

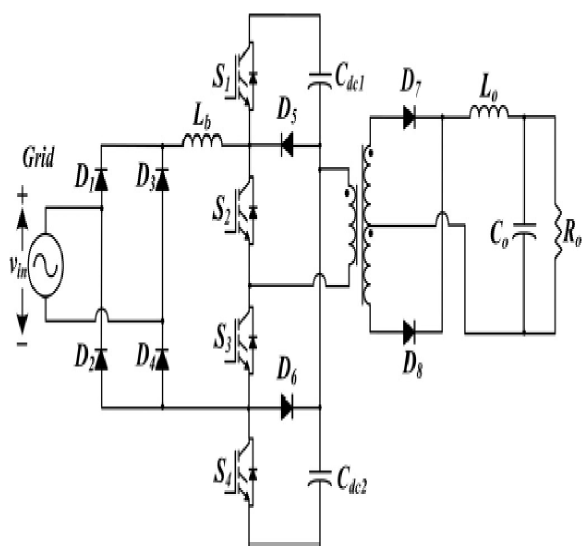

Fig.1. Proposed three-level single-stage fully integrated PFC ac–dc converter.

The flexibility in control allows optimizing power stages, fast output voltage regulation and operating with high PF and low THD. However, this method comes with the expense of more components and larger size. Moreover, the constant switching losses such as parasitic

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capacitance losses associated with power switches reduce the efficiency of the converter at light load condition. A cost-effective approach to reduce the number of switches is to use single-stage ac/dc converters [5]–[10]. In single-stage PFC converters, the front-end PFC stage and dc/dc stages are integrated and their operations are performed in a single-stage, basically, by sharing some of the switches and control scheme. An energy storage unit, capacitor or inductor, is located in between two stages, acting as a power buffer and providing sufficient hold up time. Numerous PFC ac/dc single-stage topologies have been proposed in literature, particularly, operating in discontinuous conduction mode (DCM) for simple yet effective PF control.

Majority of the proposed single-stage converters are proposed for low-power applications, where a flyback or forward converter derived topologies are used to achieve input current shaping and output voltage regulation. These converters offer cost-effective solution for low-power applications; however, they suffer from excessive voltage/current stresses on the switches, and are suitable for power levels lower than 200 W. For medium to high power applications, the research efforts have focused on ac/dc single-stage full-bridge (SSFB) converters. Current-fed SSFB converters deploy a current shaping inductor connected to the input of the diode-bridge achieving high PF; however, due to the lack of dc bus capacitor on the primary side of the transformer, the dc bus voltage is subjected to excessive overshoots and ringing. A first stage ac/dc PFC converter is worked with a switching frequency in the range of tenths to a few hundred kHz for converters made up of Si semiconductors, and from a few many kHz to tenths of MHz with wide-band crevice devices, to make the shape of the input current near sinusoidal waveform in phase with the grid voltage. The second stage dc/dc converter gives the galvanic separation and yield voltage control. The controllers of the two stages are totally independent. The adaptability in control permits enhancing power stages, quick yield voltage regulation and working with high PF and low THD. But due to extra components and big size this method is expensive. In addition the efficiency of the converter has become low at light load condition because of constant switching losses like parasitic capacitance losses. To reduce the cost of the system the number of switches involved in ac/dc converter. The capacitor or inductor unit placed between two stages will act as a power buffer. Numbers of PFC ac/dc single stage technologies have been discussed in literature, especially in PFC converter with discontinuous conduction mode. These are mainly focussed towards the low power appliances, where to produce sinusoidal input current waveform and for voltage regulation a flyback converter is used. Even though they give solution for low cost device, the voltage current stresses on the switching device are more. So these converters are applicable for low power ranges less than 200 W. Appliances which operates at medium or high power, more research works focused towards ac/dc single stage full bridge (SSFB) converters. There are two types of SSFB converters, one is Current fed SSFB and the other one is Voltage fed SSFB. In current fed SSFB to shape up the current one inductor has been employed in the input side of diode bridge and power factor is high. Since there is no dc bus capacitor on the primary side of the transformer, overshoots occur in the dc bus voltage. This drawback is not occurred in Voltage fed SSFB, because of the capacitor connected on the primary side. The proposed methodology gives solution and give maximum efficiency for low input voltage. For medium to high power applications, the research efforts have focused on ac/dc single-stage full-bridge (SSFB) converters.

2. NEED FOR POWER FACTOR CORRECTION

Conventional AC rectification is very inefficient process, resulting in waveform distortion of the current drawn from the mains. This produces a large spectrum of harmonic signals that may interfere with other equipment. These rectifier circuits will lead to main harmonic distortion and power factor issues. Line-frequency diode rectifiers convert AC voltage to DC voltage in an uncontrolled way. At higher power levels (200 to

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500 watts and higher) severe interference with other electronic equipment may become apparent due to these harmonics sent into the power utility line. Another problem is that the power utility line cabling, the installation and the distribution transformer, must all be designed to withstand these peak current values resulting in higher electricity costs for any electricity utility company. Power Factor Correction enables the equipment to maximize the active power and minimize the reactive power draw from the AC outlet.

2.1 PFC APPROACH

For the effective utilization of power supply by the equipment, different power factor correction topologies are handled. The following topologies are integrated in the proposed system. a. Active PFC approach b. Single stage PFC topology

(a) Active PFC approach

An active PFC technique is the use of power electronic devices to change the waveform of current drawn by a load to improve the power factor. Some types of active PFC are buck, boost, buck-boost and synchronous condenser. Active PFC can be single-stage or multi-stage. Many power supplies with active PFC can automatically adjust to operate on AC power from about 100V to 230V.This feature is particularly welcome in power supplies for laptops. In active power factor correction techniques approach, switched mode power supply (SMPS) technique is used to shape the input current in phase with the input voltage. Thus, the power factor can reach up to unity. By the introduction of regulation norms IEC 1000-3-2 active power factor correction technique is used now a day.

(b) Single stage PFC topology

A single-stage scheme combines the PFC circuit and dc/dc power conversion circuit into one stage. A number of single-stage circuits have been reported in recent years. Although for a singlestage PFC converter attenuation of input-current harmonics is not as good as for the two-stage approach. But it meets the requirements of IEC1000-3-2 norms. It is cost effective and compact with respect to two stage approach. Also it is simplified in structure and more efficient in low to medium power applications.

3. PROPOSED THREE-LEVEL SINGLE-STAGE PFC CONVERTER

The proposed converter is essentially an integrated version of a boost PFC circuit and three-level isolated dc–dc converter. Basically, a diode bridge and an inductor are added to the three-level isolated dc–dc converter topology as shown in Fig.2.1(a). Here, the inductor is charged when S2 and S3 are turned on simultaneously. Body diodes of S1 and S4 serve as the boost diode of the PFC boost converter. At the same time, S1 to S4 are switched to apply Vdc/2,-Vdc/2, and zero voltage across the primary side of the transformer. Thus, all of the switches are shared between the two-stages, which makes it fully integrated single-stage converter without any additional auxiliary switches. The switching scheme of the conventional three-level isolated dc/dc converter is given in Fig. 2(b). In this conventional scheme, the duty ratios of S2 and S3 are fixed close to 50% for simplicity in control and to ensure upper or lower three switches are not turned ON simultaneously as this would cause short-circuit through dc-link capacitors. Overlapping these two signals, as long as short-circuit condition is avoided, has no impact on the operation of the circuit. Similar to that in the conventional scheme, zero voltage is applied across the primary side of the transformer. This modified switching scheme is presented in Fig.2.1(c). When a boost inductor and a diode bridge is added to the nodes as in Fig.2.1(a), the overlap of gate signals of S2 and S3 enables applying input voltage across the boost inductor.

The switching scheme of the converter is given in Fig. 2. The switches S2–S3, and S1–S4 have 180° phase shift with respect to each other. The duty ratios of S2–S3 should be greater than 0.5 such that two signals overlap. Here, the circuit is explained considering that input inductor current is discontinuous and the switching scheme is as follows; S1 is turned on right after S3 is turned OFF, and similarly, S4 is turned on when S2 is turned OFF. A dead-time should be inserted in

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between the turning ON instant of S1 and turning OFF instant of S3, and likewise between switching of S2 and S4 to avoid short-circuit.

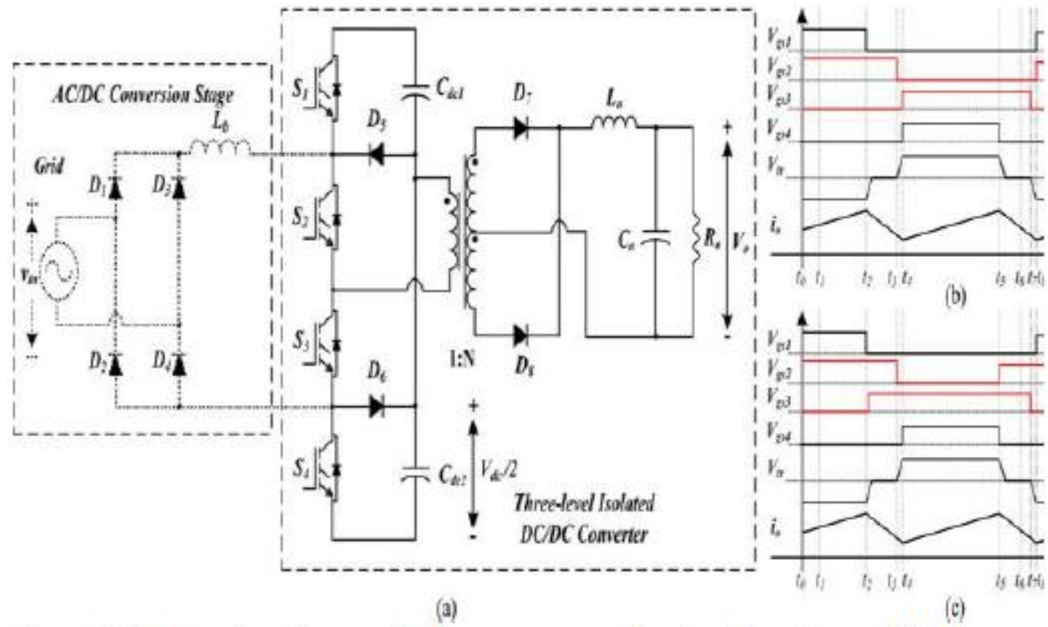

Fig. 2.1 Derivation of the proposed single-stage PFC converter; (a) topology, (b) switching scheme of the conventional three-level dc/dc converter, and (c) modified switching scheme

Converter Features

The proposed converter has the following advantages over the state-of-the-art two-stage PFC converters.

1) Less Number of Switches/Diodes: The proposed converter has the same number of switches as of three-level isolated dc/dc converter, and achieves high PF operation with only changing the switching scheme. Only a diode-bridge and a boost inductor are added to the dc/dc stage. No additional switches/diodes or switching actions have been introduced in comparison to other SSTL topologies. However, due to inherent threelevel structure, it constitutes more components in comparison to SSFB topologies.

2) Flexible DC-LinkVoltage: Since the proposed single-stage converter is essentially derived from a three-level converter, the voltages across the switches are halved in comparison to that of the full-bridge derived or two-stage topologies. This brings more flexibility in choosing the dc-link voltage and thereby, designing the parameters. At high dc-link voltage, the efficiency of the converter decreases in DCM; however, as it is analyzed in the following section, higher dc-link results in achieving higher PF.

CONCLUSION

Thus, a three-level single-stage PFC ac/dc converter is proposed for low-power applications. The proposed converter exhibits high PF with less number of switches/diodes, operated at constant duty ratio. A PFC inductor and a diode bridge are added to the conventional three-level isolated dc/dc converter, while the switching scheme is modified to be compatible with single-stage operation. The input current ripple frequency is twice of the switching frequency contributing to using smaller PFC inductor. The results of the analyses show that less than 265 V line voltage, the PF can be increased to 0.99 from 0.88.

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