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A NEW INTERLEAVED THREE-PHASE SINGLE-STAGE PFC AC-DC CONVERTER WITH FLYING CAPACITOR

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Abstract— A new interleaved three-phase PFC AC-DC sing e-stage multilevel is proposedin this paper. The proposed converter can operate with reduced input current ripple and peak switch currents due to its interleaved structure, a continuous output inductor current due to its three-level structure, and improved light-load efficiency as some of its switches can be turned on softly. In the paper, the operation of the converter is explained, the steady-state characteristics of the new converter are determined and its design is discussed. The feasibility of the new converter is confirmed with experimental results obtained from a prototype converter and its efficiency is compared to that of another multilevel converter of similar type.

Index Terms— AC-DC power factor correction, Single-stage converters, Three-Phase Systems, Three level converters, Phaseshifted modulation.

I. INTRODUCTION

AC-DC power supplies need to be implemented with some sort of input power factor correction (PFC) to comply with harmonic standards such as IEC 1000-3-2 . PFC techniques can generally beclassified as follows:

• Passive methods that use inductors and capacitors to filter out low frequency input current harmonics to make the input current more sinusoidal. Although these converters implemented with such PFC are simple and inexpensive, they are also heavy and bulky and thus passive methods are used in a limited number of applications.

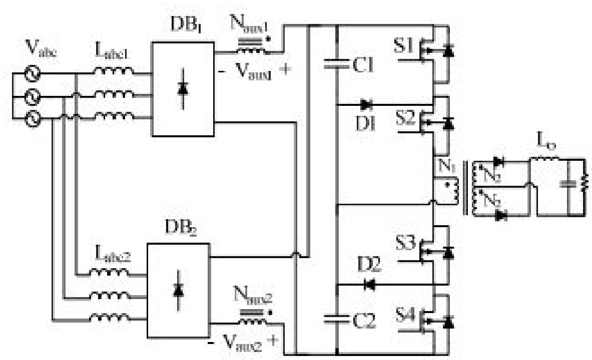
• Two-stage converters that use a pre-regulator to make the input current sinusoidal and to control the intermediate DC bus voltage along with a DC-DC converter to produce the desired output voltage. Such converters, however, require two separate switch-mode converters so that the cost, size, and complexity of the overall ac-dc converter is increased.

• Single-stage power-factor-corrected (SSPFC) converters that have PFC and isolated DC-DC conversion in a single power converter so that they are simpler and cheaper than two-stage converters. Several single-phase converters have been proposed in the literature, with three-phase converters being preferred over single-phase converters for higher power applications. Previously proposed three-phase single-stage AC-DC converters, however, have at least one of the following drawbacks that have limited their widespread use:

- They are implemented with three separate AC-DC single-stage modules [5]-[7], which increases cost and introduces issues related to the synchronization of all three modules.

- The converter must be implemented with switches and bulk capacitors with very high voltage ratings as they are exposed to very high voltages
- The converter has difficulty performing PFC and DCDC conversion simultaneously, which results in significant input current distortion
- The converter must be controlled using very sophisticated techniques and/or non-standardtechniques This is especially true of resonant type converters that need variable switching frequency control methods to operate.
- The converter has a very high output ripple as its output current must be discontinuous. Secondary diodes with high peak current ratings and large output capacitors to filter the ripple are needed
- There is a need to have a large input filter to filter out large input current ripple as this current is discontinuous with high peaks

A three-phase, single-stage three-level converter proposed in mitigates these drawbacks. Although the converter proposed in that paper was an advance over previously proposed three-phase single-stage converters, it still suffered from the need to have a discontinuous output inductor current at light load conditions to keep the DC bus capacitor voltage less than 450V and it needed tooperate with discontinuous input current, which resulted in high component current stress and the need for significant input filtering due to the large amount of ripple. The topology proposed in is an interleaved three-phase, single-stage converter that has an interleaved structure, which thisstructure is a very popular structure in power electrons converters . The topology in also has an output current that is continuous for almost all load ranges, a DC bus voltage that is less than 450 for all load conditions and a superior input current harmonic content. In this paper, a new interleaved three-phase single-stage PFC AC-DC converter that uses flying capacitor structure with standard phase-shift PWM, are



presented to improve efficiency ofthe converter particularly at light load conditions. The operation of the converter is explained, the steady-state characteristics of the new converter are determined and its design is discussed. The feasibility of the new converter is confirmed with experimental results obtained from a prototype converter and its efficiency is compared to that of another multilevel converter of similar type.

II. CONVERTER TOPOLOGY

The converter and its key waveforms The proposed converter uses auxiliary windings that are taken from the converter transformer to act as "magnetic switches" to cancel the DC

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bus capacitor voltage so that the voltage that appears across the diode bridge output is zero. Auxiliary Winding 1 (Naux1/N1=2) cancels out the DC bus voltage when the primary voltage of the main transformer is positive, so that the output voltage of Diode Bridge 1 (DB1) is zero and the currents in input inductors La1, Lb1, and Lc1rise. Auxiliary Winding 2 (Naux2/N1=2) cancels out the DC bus voltage when the primary voltage of the main transformer is negative, so that the output voltage of Diode Bridge 2 (DB2) is zero and the currents in input inductors La2, Lb2, and Lc2rise. When there is no voltage across the main transformer primary winding, the total voltage across the DC bus capacitors appears at the outputof the diode bridges and the input currents falls since this voltage is greater than the input voltage. If the input currents are discontinuous, the envelope of the input current will be sinusoidal and in phase with the input voltages. The converter has the following modes of operation during a half switching cycle; equivalent circuit diagrams that show the converter's modes of operation Mode 1 (t0< t < t1): During this interval, switches S1and S2are ON. It should be noted that both DC bus capacitors and the flying capacitor are charged to half of the DC bus voltage. In this mode, energy from DC bus capacitor C1flows to the output load. Due to magnetic coupling, a voltage appears across Auxiliary Winding 1 that is equal to the DC bus

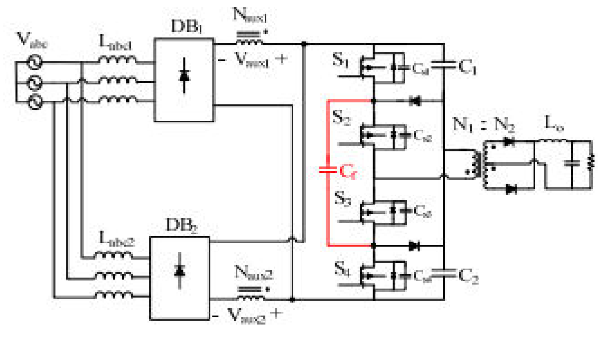
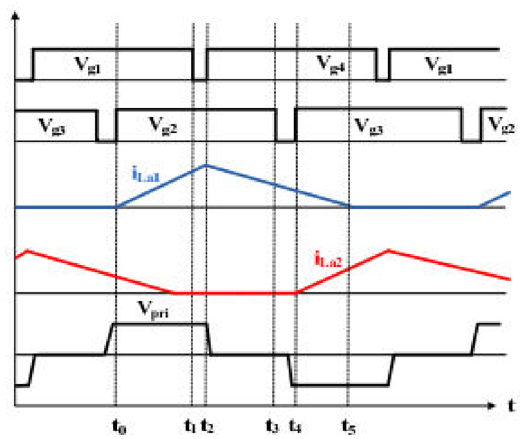


Fig. 2. Proposed single-stage three-level ac-dc converter.



voltage, but with opposite polarity. This voltage cancels the total DC bus capacitor voltage so that the voltage at the diode bridge output is zero and the input currents in La1, Lb1, and Lc1rise. Mode 2 (t1< t < t2): In this mode, S1is OFF and S2 remains ON. Capacitor Cs1charges and capacitor Cs4discharges through Cfuntil the voltage across Cs4, the output capacitance of S4, is clamped to zero. The energy stored in the input inductor during the previous mode starts being transferred into the DC bus capacitors. This mode ends when S4turns on with ZVS. Mode 3 (t2< t < t3): In Mode 3, S1is OFF and S2remains ON. The energy stored in input inductor L1during Mode 1 is transferring into the DC bus capacitors. The voltage that appears across Auxiliary Winding 1 is zero. The primary current of the

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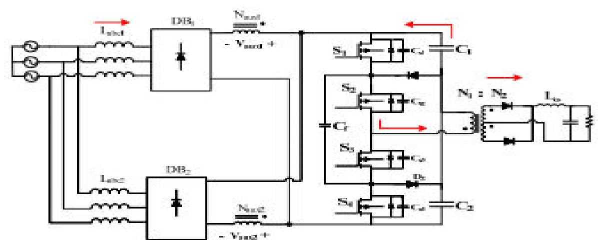
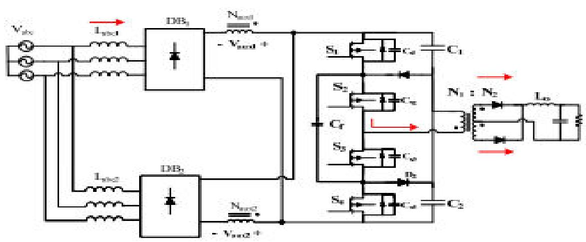
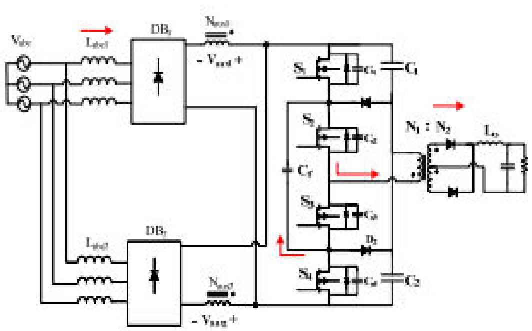
main transformer circulates through D1and S2. With respect to the converter's output section, the load inductor current freewheels in the secondary of the transformer, which defines a voltage across the load filter inductor that is equal to –VL.

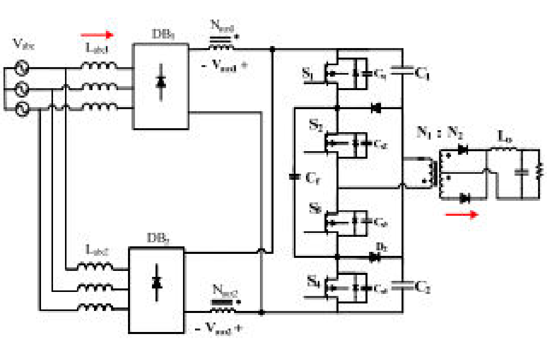


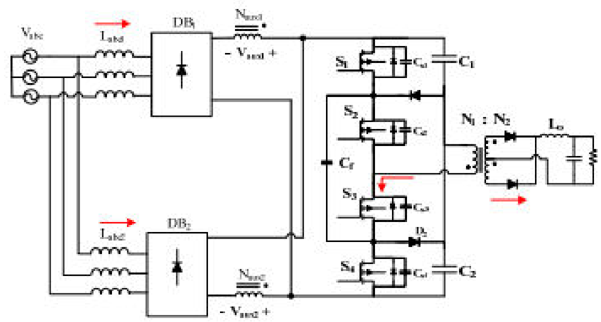
(a) Mode 1 ($t_0 < t < t_1$)





(b) Mode 2 ($t_1 < t < t_2$)





CONVERTER ANALYSIS

The analysis and design of the proposed converter is almost identical to that presented and is therefore are not presented here, in detail. Only graphs of key characteristic curves and general design guidelines are presented in this paper. The reader is referred details. In order to analyze and determine the steady-state operating points of the converter, a computer program such as the one presented Graphs of steady-state characteristics as part of a design procedure. These graphs help to find out the appropriate parameter values based on the defined operating point. Assuming ideal operation to simplify the analysis, the characteristic curves of the proposed converterThis is because in this case, the flying capacitor just affects the transition modes of the converter and does not affect the overall steady state operation of the proposed converter.

CONCLUSION

A new interleaved three-phase,three-level, single-stage power-factor-corrected AC-DC converter using standard phase-shift PWM was presented in this paper. In this paper, the operation of the converter was explained and its feasibility was confirmed with experimental results obtained from a prototype converter. The efficiency of the new converter was compared to that of another converter of the same type. It was shown that the proposed converter has a better efficiency, especially under light-load conditions, and it was explained that this is because energy from the output inductor can always be used to ensure that the very top and the very bottom switches can be turned ON with ZVS, due to a discharge path that is introduced by its flying capacitor.

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