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A THREE PHASE AC TO DC CONVERTER WITH FLYING CAPACITOR

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ABSTRACT

A Three phase ac-dc converter that uses flying capacitor structure with standard phase-shift pulse width modulation is presented to improve the efficiency of converter at light load conditions. The proposed converter has an auxiliary circuit to cancel the capacitor voltage to make the input inductor acts as a boost inductor to have a single-stage PFC. The proposed interleaved topology with flying capacitor can guarantee a ZVS turn of switches. Due to the interleaved structure converter can operate with reduced input current ripple and peak switch current and improved light load efficiency as some of its switches can be turned ON softly. The converter deals with a new single stage three level ac-dc converter which performs both power factor correction and voltage regulation.

Index Terms— *AC–DC power factor correction, phase-shifted modulation, single-stage converters, three-level converters, three phase systems.*

I INTRODUCTION

AC-DC power supplies implemented with input power factor correction such that the power supply will satisfy the harmonic standards like IEC 1000-3-2[1]. The PFC techniques can be classified as follows:

1) In passive methods, inductors and capacitors are used to filter out low-frequency input current harmonics to make the input current more sinusoidal. These converters are simple and inexpensive, but they are also heavy and bulky. Thus passive

methods are used in a limited number of applications.

2) In the two-stage converters, pre-regulator is used 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 require two separate switch-mode converters so that the cost, size, and complexity of the overall ac–dc converter increased.

3) 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 [2]–[4] and three-phase [5]–[10] converters have been proposed in the literature. Three-phase converters preferred over single-phase converters for higher power applications.

Previously proposed three-phase single-stage ac–dc converters, have some of the following drawbacks that have limited their widespread use:

1) They used three separate ac–dc single stage modules [5]–[7] hence the synchronization of all the three modules is difficult, and the cost gets increased.

2) The converter is implemented with switches and bulk capacitors which have very high-voltage ratings as they are exposed to very high voltages [9], [10].

3) The converter cannot perform PFC and dc–dc conversion simultaneously, which results in significant input current distortion [8].

4) The converter must be controllable using sophisticated techniques and non-standard techniques [2]–[4]. This is especially true of resonant-type converters that need variable switching frequency control methods to operate.

5) The converter has a high output ripple as its output current must be discontinuous. To filter the ripple, secondary diodes with high peak current ratings are needed [5]–[11].

6) 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 [5], [6], [9], [10].

A three-phase, single-stage three-level converter proposed in [6] have the above drawbacks. Although the converter proposed in that paper was an advance over previously proposed three-phase converters, but the output inductor current should be discontinuous for light load conditions to have dc bus capacitor voltage less than 450. Due to the operation of discontinuous current filtering is required to remove the ripple. The topology proposed in [9], is an three-phase single-stage converter that has an interleaved structure. The topology in [9] 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 pulse width modulation (PWM) is presented to improve the efficiency of the converter particularly at light-load conditions.

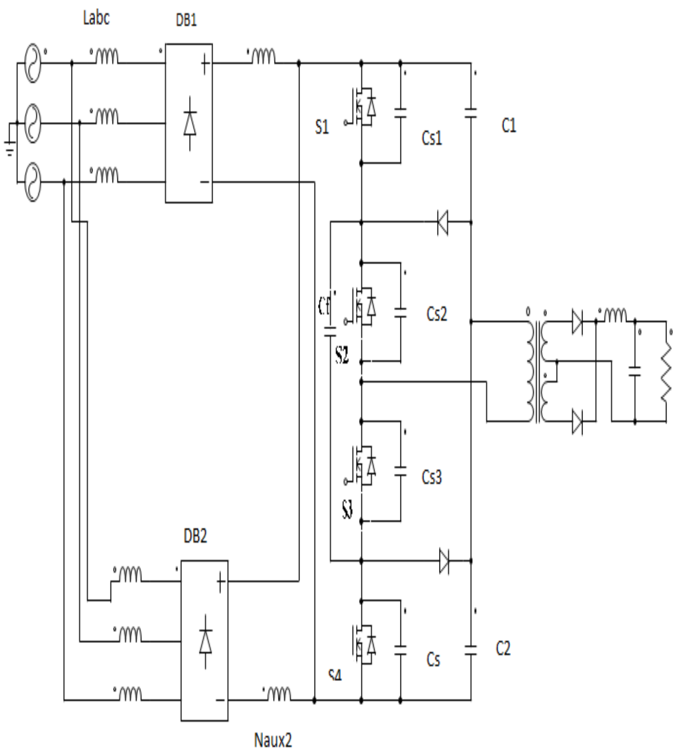

Fig 1 proposed simulation circuit

II. CONVERTER TOPOLOGY

In the proposed converter auxiliary windings are taken from the converter transformer. These windings will behave like magnetic switches. These windings are used to cancel the dc bus capacitor voltage. This is done to have zero voltage across the diode bridge. Auxiliary Winding 1 (Naux1/N1 = 2) will cancel the dc bus voltage when the main transformer primary voltage of the main transformer is positive. As a result, the output voltage of Diode Bridge 1 (DB1) is zero, and the currents in input inductors La1, Lb1, and Lc1 will rise. Auxiliary Winding 2 (Naux2/N1 = 2) is used to cancel the dc bus voltage when the main transformer primary voltage of is negative. Hence the output voltage of Diode Bridge 2 (DB2) will be zero, and the currents in input inductors La2, Lb2, and Lc2 will begin to rise. When the voltage across the main transformer primary winding is zero, the total voltage across the dc bus capacitors appears at the output of the diode bridges, and the input currents will begin to fall, because this voltage is greater than the input voltage. The converter has the following modes of operation

Mode 1 ($t0 \leq t \leq t1$): During this interval, switches S1 and S2 are 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 C1 flows to the output load. Due to magnetic coupling, a voltage appears across Auxiliary Winding 1 that is equal to the dc bus 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 Lc1 rise.

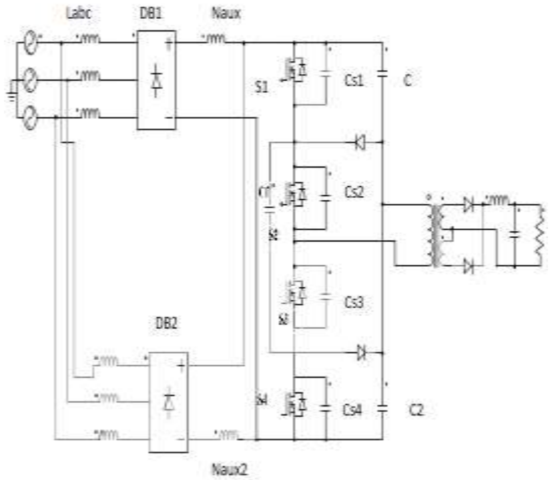

Fig 2 Equivalent circuit for mode 1

Mode 2 ($t1 \leq t \leq t2$): In this mode, S1 is OFF, and S2 remains ON. Capacitor Cs1 charges and capacitor Cs4 discharges through Cf until 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 S4 turns ON with ZVS.

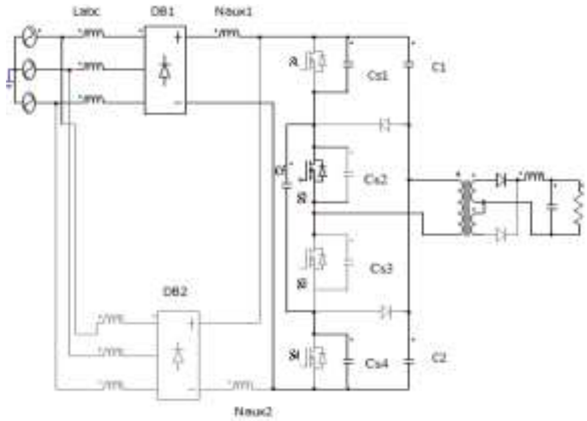

Fig 3 Equivalent circuit for mode 3

Mode 3 ($t2 \leq t \leq t3$): In Mode 3, S1 is OFF, and S2 remains ON. The energy stored in input inductor L1 during Mode 1 is transferring into the dc bus capacitors. The voltage that appears across Auxiliary Winding 1 is zero. The primary current of the main transformer circulates through D1 and 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.

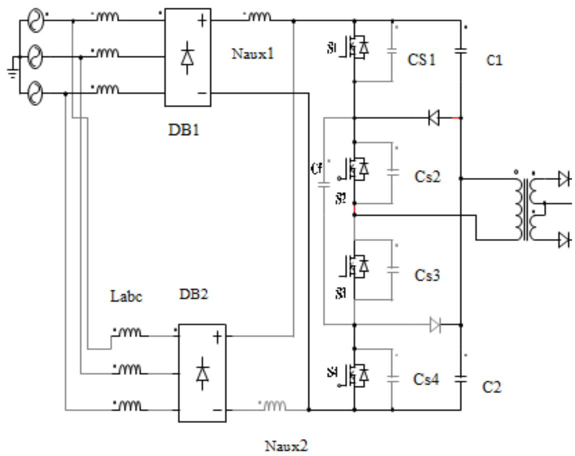

Fig 4 Equivalent circuit for mode 3

Mode 4 (t3 ≤ t ≤ t4): In this mode, S1 and S2 are OFF. The energy stored in L1 will be transferred into the dc bus capacitor. The primary current of the transformer discharges through the output capacitor Cs3. If there is enough energy in the leakage inductance, the primary current will completely discharge the body capacitor of Cs3 , and current will flow through the body diode of S3.This current also chargesC2 through the body diodes of S3 and S4. Switch S3 is switched ON at the end of this mode.

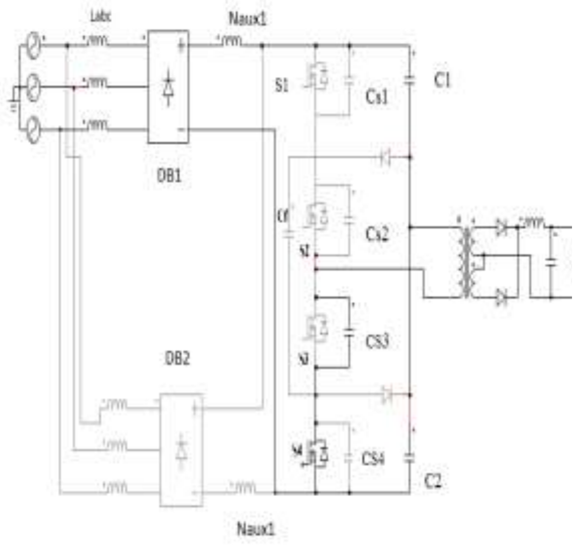

Fig 5 Equivalent circuit for mode 4

Mode 5 (t4 ≤ t ≤ t5): In this mode, S3 and S4 are ON, and energy flows from capacitor C2 to the load. Voltage appears across Auxiliary Winding 2 that is equal to the dc bus voltage, but with opposite polarity to cancel out the dc bus voltage. The voltage across the boost inductors L2 (L2 = Labc2) becomes only the rectified supply voltage of each phase and the current flowing through each inductor increases. This mode ends when the energy stored in L1 is completely transferred into the dc bus capacitor.

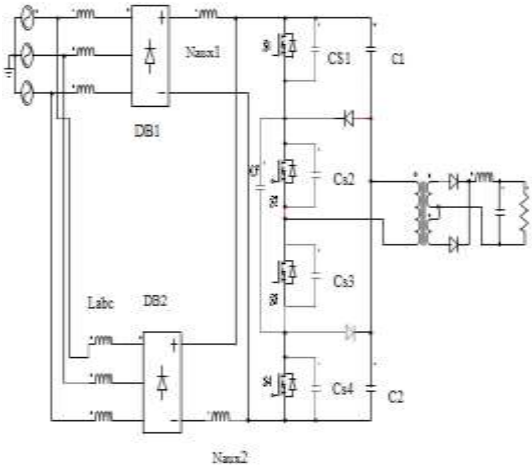

Fig 6 Equivalent circuit for mode 5

For the remaining of the switching cycle, the converter goes through Modes 6–10, which are identical to Modes 1–5 except that S3 and S4 are ON instead of S1 and S2 and DB2 conducts current instead of DB1. The input current is the sum of currents iL1 and iL2, corresponding to each set of input inductors, with each inductor having a discontinuous current. However, by selecting appropriate values for La1 = Lb1 = Lc1 and La2 = Lb2 = Lc2, two inductor currents such as iLa1 and iLa2 can be made to overlap each other so that the input current can be made continuous, thus reducing the size of input filter significantly. There is a natural 180° phase difference between the currents in L1 and the currents in L2 as one set of currents rises when the transformer primary is impressed with a positive voltage, and the other set rises when the transformer primary is impressed with a negative voltage. Switches S2 and S3 are not allowed to be ON at the same time, and switches S1 and S4 are not allowed to be ON simultaneously as well. The converter is in an energy-transfer mode whenever switches S1 and S2 are ON, or S3 and S4 are ON. It is in a freewheeling mode of operation whenever switches S1 and S3 or S2 and S4 are ON. The sequence of alternating energy transfer and freewheeling modes that occur during a switching cycle corresponds to the same sequence of modes that exists in a standard two-level phase-shift PWM full-bridge converter.

III. SIMULATION RESULTS

The feasibility of the proposed three-phase AC-DC converter with flying capacitor was verified with MATLAB; a commercially available software package for power electronic simulations. Figure 6.1 shows the MATLAB simulation circuit of proposed circuit. The circuit is drawn using MATLAB software components. Now assign the parameter values for each component in the circuit diagram. In order to measure voltage and current of power device and load, voltage measurement, and current measurement blocks are used. Digital values of voltage and current are displayed by using the display block present in the Simulink. Finally, set the run time value and run the simulation. Simulation results can be viewed by using the scope in the Simulink library.

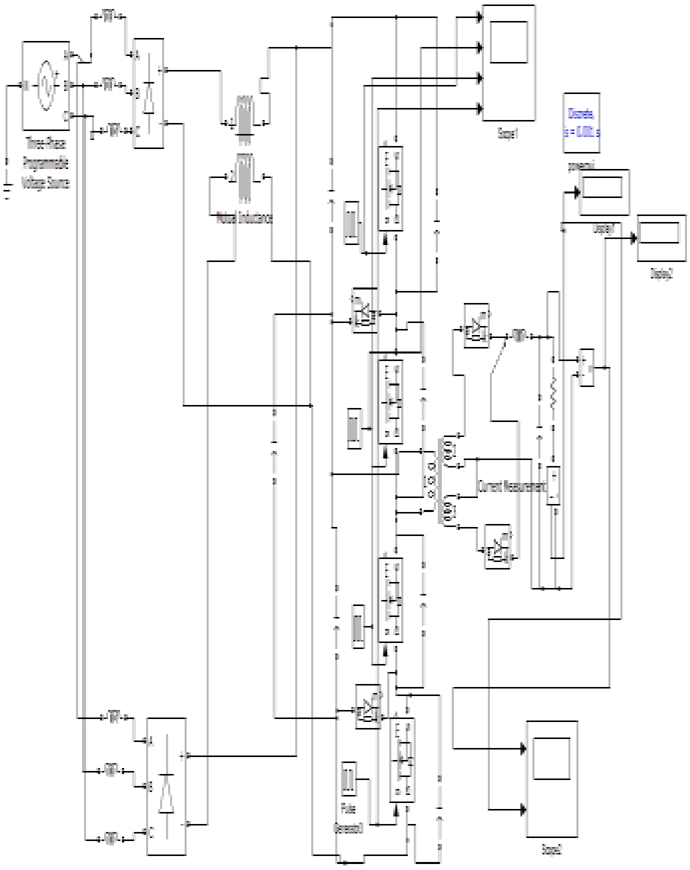

Fig 7 Simulation circuit of the proposed converter

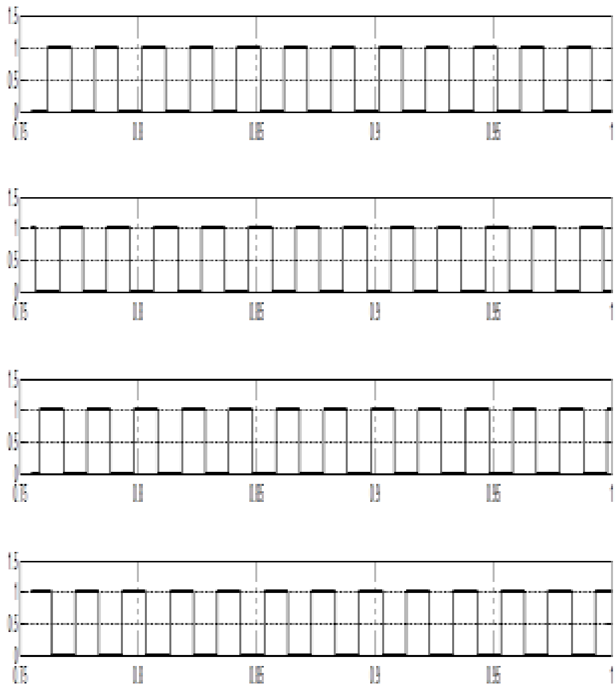

Fig 8 Gate pulses for the MOSFET

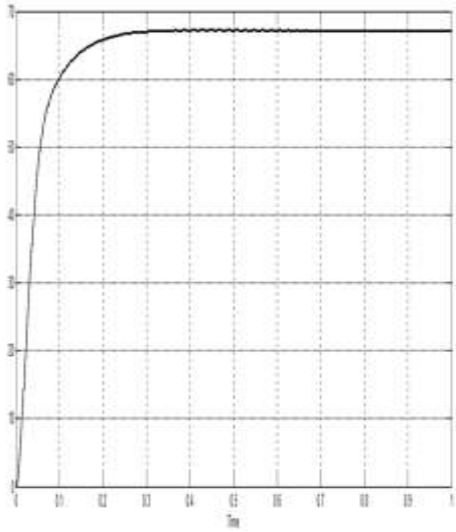

Fig 9 Output voltage for the proposed converter

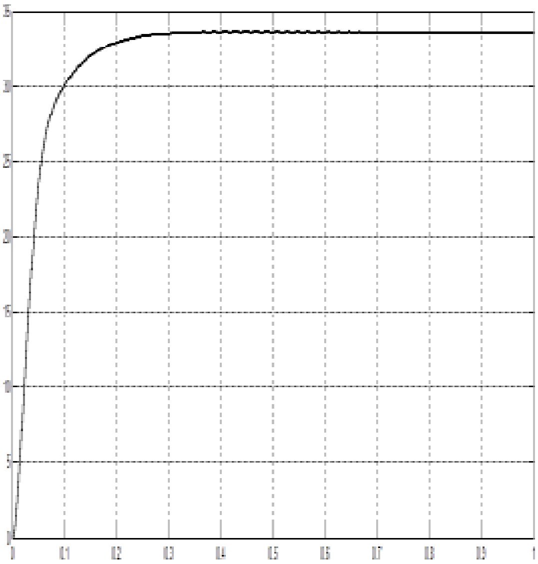

Fig 10 Output current for the proposed converter

IV. CONCLUSION

The new three-phase AC-DC converter is proposed in this thesis. The converter operates with a single controller to regulate the output voltage and uses auxiliary windings taken from its power transformer as magnetic switches to cancel the dc bus voltage so that the input section operates as a boost converter. The proposed converter can operate with lower peak voltage stresses across its switches and the dc bus capacitors as it is a three-level converter. The output inductor of the proposed converter can be designed to work in continuous conduction mode over a wide range of load variation and input voltage. This result in a lower output inductor current ripple which helps to reduce secondary component stresses and filtering. High conversion efficiency over 96% can be achieved.

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