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Volume 07, Issue 03, Pages: 12–19.

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SIMULATION OF THREE PHASE INTERLEAVED PFC AC-DC CONVERTER WITH CLOSED LOOP OPERATION

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Abstract- That operates with a single controller to regulate the output voltage and the input inductor act as a boost inductor to have a single stage power factor correction with good output response. The paper deals with a new single stage three level ac-dc converter which performs both power factor correction and voltage regulation in a single stage. The proposed converter has two separate controllers, one for power factor correction and the other for regulating the output voltage. A comprehensive review of the existing single stage topologies has been carried out. Then the operating principle, control scheme and the design of the new converter are presented. The proposed converter is having an input power factor close to unity and better voltage regulation compared to the conventional ac-dc converter topologies. Proposed topology is evaluated through Matlab/Simulink platform and simulation results are conferred.

Keywords: Power Factor Correction, Single Stage Converters, AC–DC Power Factor Correction, Three Level Converters, Closed Loop Control Logic.

I.INTRODUCTION

Power electronic converters operating from the utility mains can generate current harmonics that are injected into the mains. The dramatic growth in the use of electrical equipment in recent years has resulted in a greater need to limit these harmonics to meet regulatory standards. This can be done by some form of power factor correction (PFC) to shape the input phase currents so that they are sinusoidal and in phase with the phase voltages. Three-phase PFC is typically done by using a six-switch converter either to process the bulk of the power fed to the load or to be an active filter that processes only a portion of the power fed to the load. Using a six-switch converter, however, is costly and complicated given the number of active switches that must be used and the sophisticated control needed to ensure a good power factor. Cheaper and simpler methods of performing three-phase active input PFC have been developed using converters with less than six switches [1]–[8]. One such converter, first proposed in [7], is a single-switch boost converter that can be designed to operate so that its line currents operate in the discontinuous conduction mode and are bounded by a sinusoidal envelope. Many three-phase ac–dc converters that perform PFC with a reduced number of switches share variations of the converter proposed in [7] and their output voltage is always higher than their input voltage because they are boost-type converters. This is a drawback if there is a need for a converter that needs to operate for a wide range of input ac voltages and/or produce range of output dc voltages such as a front-end rectifier for a commercial product that must work with several ranges of ac voltages. Relatively few reduced switch three-phase ac–dc buck–boost rectifiers

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have been proposed in the power electronics literature [9]–[15] mainly due to topological constraints.In order to reduce the cost, size, and complexity associated with two-stage ac–dc power conversion and PFC, researchers have tried to propose single-stage converters that integrate the functions of PFC and isolated dc–dc conversion in a single power converter. Several single-phase [5]–[10] and three-phase [4] 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.

1) They are implemented with three separate ac–dc single stage modules

2) The converter components are exposed to very high dc bus voltages so that switches and bulk capacitors with very high voltage ratings are required.

3) The input currents are distorted and contain a significant amount of low-frequency harmonics because the converter has difficulty performing PFC and dc–dc conversion simultaneously.

4) The converter must be controlled using very sophisticated techniques and/or nonstandard techniques [5]–[11]. This is particularly true for resonant-type converters that need variable-switching-frequency control methods to operate.

5) The output inductance must be very low, which makes the output current to be discontinuous. This results in a very high output ripple so that secondary diodes with high peak current ratings and large output capacitors to filter the ripple are needed.

6) Most of them are in discontinuous conduction mode at the input and need to have a large input filter to filter out large high-frequency harmonics [4].

II. THE SINGLE STAGE POWER FACTOR CORRECTED TOPOLOGIES

One classification of the SSPFC circuits is based on the number of switches in the converter. The SSPFC circuits provide the features of the power factor pre-regulators in addition to those of dc-dc converters cascaded with it. The basic SSPFC circuit was introduced in early 1990s by Madigan. This was achieved by integrating the boost input shaping converter with either a fly-back or a forward topology.

A. Single switch topologies

Many single switch single stage converter topologies have been proposed. A single stage ac-dc converter is proposed in which the dc voltage is less dependent on the operating conditions. But the voltage stress is more on the switch. Also it contains low frequency output voltage ripples. The various problems associated with single switch topologies are lower power factor at low line input, dead angle problem of input current high capacitor voltage stress and higher switch voltage.

B. Two switch topologies

Half bridge converters have also been integrated in SSPFC topologies either in symmetrical or asymmetrical modes of operation. They are able to provide high input power factor. Still they suffer from high circulating currents, high dc bus voltages or discontinuous currents.

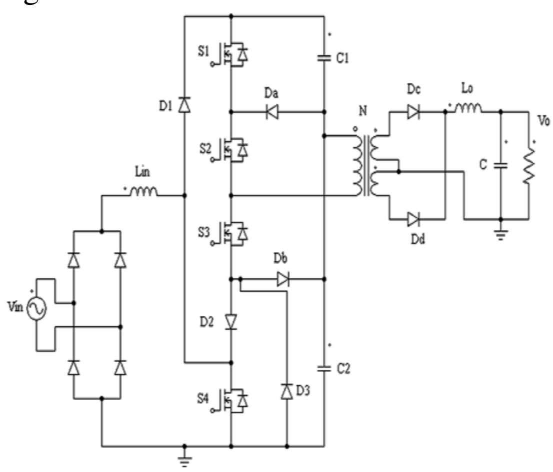

Fig.1 Proposed three level single stage converter

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The topology proposed in has an auxiliary circuit which is used to get a reduced capacitor voltage stress. Here the converter is operated in DCM, thus achieving high input power factor. But the current stress on the converter switches becomes high. Thus the conduction losses increase resulting in lower efficiency. Hence these converters cannot be used for higher power applications.Fig.1 shows a new three level single stage converter which eliminates the limitations of the previous topologies. It consists of a boost converter section and an isolated forward converter section. The authors proposed a three-phase single-stage three-level converter to mitigate 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<450 V, and it needed to operate 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.This paper presents a new interleaved three-phase single stage rectifier that does not have any of these drawbacks. The work presented in this paper can be considered to be a follow-up work in relation to what was presented. In comparison to the converter presented, the converter presented in this paper has an interleaved structure, requires two fewer diodes in the dc bus, has an output current which is continuous for all load ranges, has a dc bus voltage that is less than 450 V for all load conditions, and has a much better input current harmonic content. In this paper, the operation of the new converter is explained; its features and design are discussed.

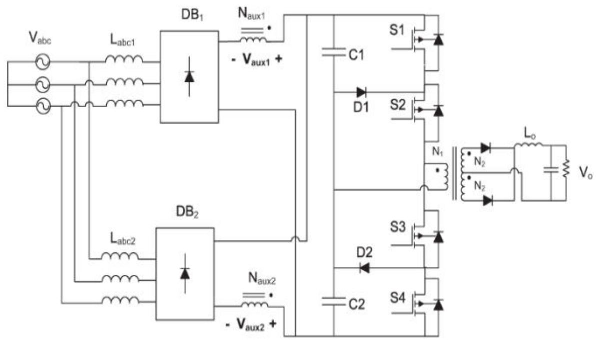


Fig.2 Proposed interleaved three-phase three-level converter.

Several SSPFC topologies have been introduced so far by various power electronic researchers. In the next section a review of the various SSPFC topologies is been carried out.

III. PROPOSED CONVERTER OPERATION

The proposed converter and its key waveforms are shown in Figs. 2 and 3, respectively. The proposed converter uses auxiliary windings that are taken from the converter transformer to act as "magnetic switches" to cancel the dc bus capacitor voltage so that the voltage that appears across the diode bridge output is zero. When the primary voltage of the main transformer is positive, auxiliary winding 1 (Naux1/N1=2) cancels out the dc bus voltage so that the output voltage of diode bridge 1(DB1) is zero and the currents in input inductors La1, Lb1, and Lc1 rise. When the primary voltage of the main transformer is negative, auxiliary winding 2 (Naux2/N1=2) cancels out the dc bus voltage so that the output voltage of diode bridge 2(DB2) is zero and the currents in input inductors La2, Lb2, and Lc2 rise. When there is no voltage across the main transformer primary winding, the total voltage across the dc bus capacitors appears at the output of the diode bridges and the input currents fall 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 modes of operation are explained in this section. The typical converter waveforms are shown in Fig. 3. The equivalent circuit in each stage is shown in Fig. 4. The converter goes through the following modes of operation.

Mode 1(t0<t<t1)[Fig. 4(a)]: During this interval, switches S1andS2are ON. In this mode, the energy from dc bus capacitorC1 flows to the output load. Due to magnetic coupling, a voltage appears across auxiliary winding 1 which is equal to the dc bus voltage but has opposite polarity and cancels the total dc bus capacitor voltage; the voltage at the diode bridge output is zero, and the input currents inLa1,Lb1, andLc1rise.

Mode 2(t1<t<t2) [Fig. 4(b)]: In this mode, S1 is OFF, and S2 remains ON. The energy stored in L1(L1=Labc1) during the previous mode starts to transfer into the dc bus capacitors. The voltage that appears across auxiliary winding 1 is zero. The primary current of the main transformer circulates throughD1 andS2. 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 equal to−VL.

Mode 3(t2<t<t3)[Fig. 4(c)]: In this mode,S1 and S2 are OFF. The energy stored inL1still is transferring into the dc bus capacitor. The primary current of the transformer charges C2 through the body diodes of S3and S4. Switches S3andS4are switched ON at the end of this mode.

Mode 4(t3<t<t4) [Fig. 4(d)]: In this mode, S3 andS4 are ON, and the energy flows from capacitor C2 into the load. The voltage appears across auxiliary winding 2 which is equal to the dc bus voltage but acts like a magnetic switch and cancels 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 inL1completely transfers into the dc bus capacitor. For the remainder of the switching cycle, the converter goes through modes 1–4 but with S3andS4 ON instead ofS1andS2and with DB2instead of DB1.

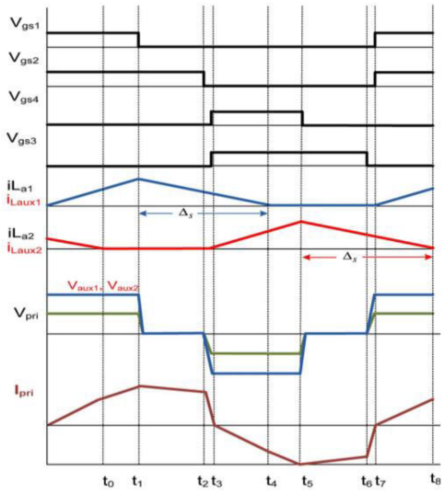
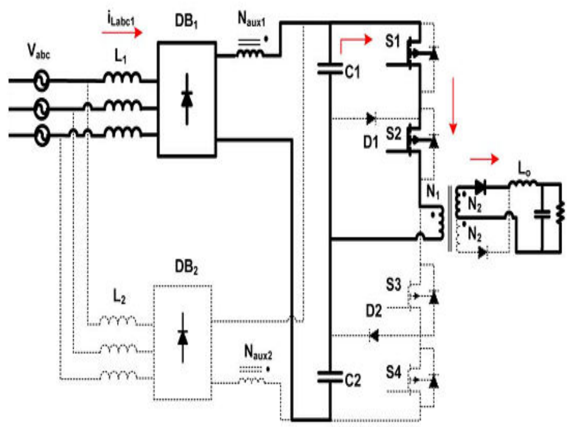
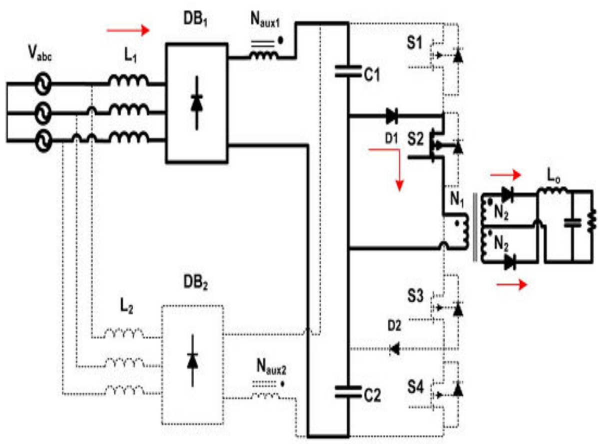


Fig.3 Typical waveforms describing the modes of operation



(a)



(b)

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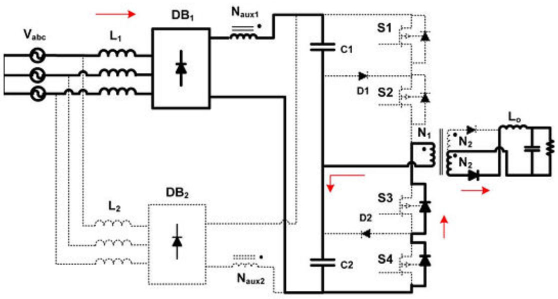
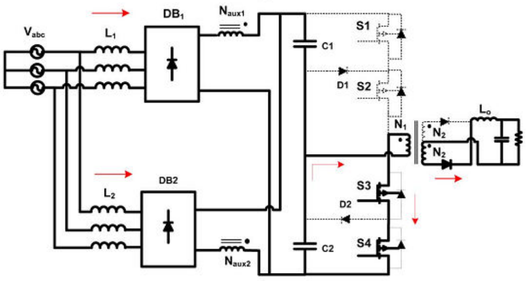
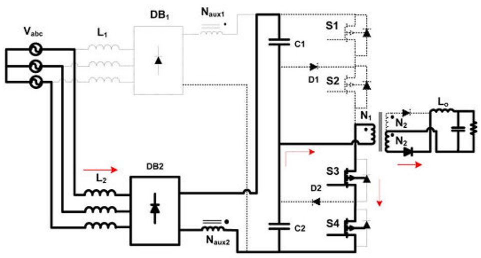


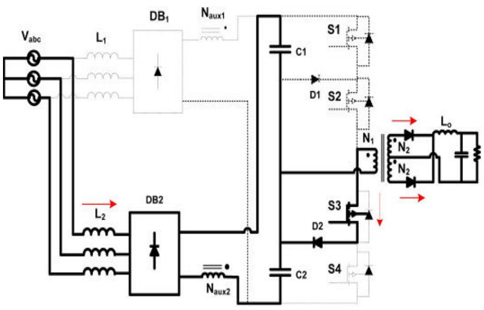
(c)



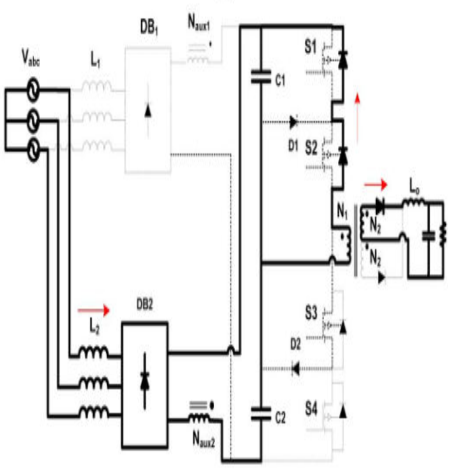
(d)



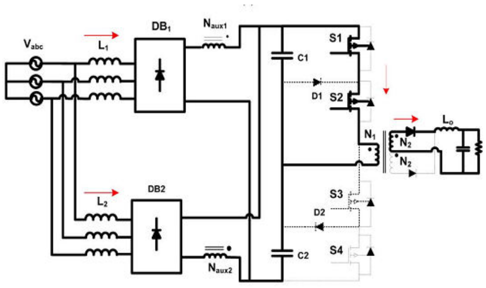
(e)



(f)



(g)



(h)

Fig. 4. Modes of operation. (a) Mode 1(t0<t<t1). (b) Mode 2 (t1<t<t2). (c) Mode 3 (t2<t<t3). (d) Mode 4 (t3<t<t4). (e) Mode 5 (t4<t<t5). (f) Mode 6(t5<t<t6). (g) Mode 7(t6<t<t7). (h) Mode 8(t7<t<t8)

Mode 5(t4<t<t5) [Fig. 4(e)]: In this mode, S3 and S4 are ON, and a symmetrical period begins. In this mode, the energy flows from capacitor C2 into the load. The voltage across the boost inductors L2 becomes only the rectified supply voltage of each phase, and the current flowing through each inductor increases.

Mode 6(t5<t<t6) [Fig. 4(f)]: In this mode, S3 is ON and S4 is OFF, and the primary current of the main transformer circulates through diodeD2 andS3. The energy stored in the boost inductors L2during the previous mode starts transferring into the dc bus capacitor. The output inductor current also freewheels in the secondary of the transformer during this mode.

Mode 7(t6<t<t7)[Fig. 4(g)]: In this mode,S3andS4are OFF, and the primary current of the transformer charges capacitorC1through the body diodes of S1andS2.The energy stored in the boost inductorsL2transfers into the dc bus capacitor.

Mode 8(t7<t<t8)[Fig. 4(h)]: In this mode,S1and S2are ON. In this mode, the energy from dc bus capacitor C1 flows to the output load. This mode ends when the energy in the inductors L2 completely transfers into the dc bus capacitors. Time t8 is the end of the switching cycle, and another switching cycle begins with the same modes

It should be noted that the input current is the summation of inductor currentsiL1andiL2which are both discontinuous. However, by selecting appropriate values forL1 (=La1=Lb1=Lc1)andL2(=La2=Lb2=Lc2)in such a way that two inductor currents such as iLa1andiLa2have to overlap each other, the input current can be made continuous as shown in Fig. 5, thus reducing the size of the input filter significantly.

There is a natural 180◦phase difference between the currents in L1and the currents inL2as 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—these two events occur 180◦apart during a switching cycle.

IV. CONVERTER ANALYSIS AND DESIGN

The analysis and the design of the proposed interleaved converter are almost identical to that presented and therefore are not presented here. Readers are referred for details. In this paper, only differences in the analysis and the design are presented.With respect to analysis, steady-state operating points are identified using a computer program such as the one presented. The only difference between the analysis of the proposed converter and the one is the analysis and design of the input inductors. In the proposed interleaved converter, there are two sets of inductors (L1 andL2) at the input side, with each set conducting half the current. The analysis needs to consider the current in both these sets instead of just one.

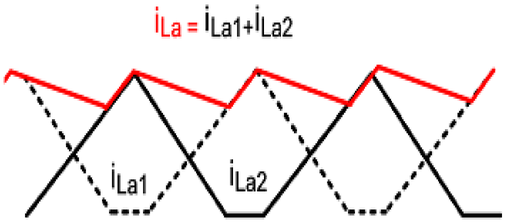


Fig.5 Interleaving between two input inductor currents

The values forL1andL2should be low enough to ensure that their currents are fully discontinuous under all operating conditions but not so low as to result in excessively high peak currents. The worst case to be considered is the case when the converter operates with minimum input voltage and maximum load since, if the input current in each set of inductors is discontinuous under these conditions, it will be discontinuous for all other operating conditions, and thus, an excellent power factor will be achieved.

V.SIMULATION RESULTS

Here simulation is carried out in several cases, in that 1). Design of Open-Loop Circuit of Proposed AC-DC Converter, 2). Design of Closed-Loop Circuit of Proposed AC-DC Converter.

Case 1: Design of Open-Loop Circuit of Proposed AC-DC Converter

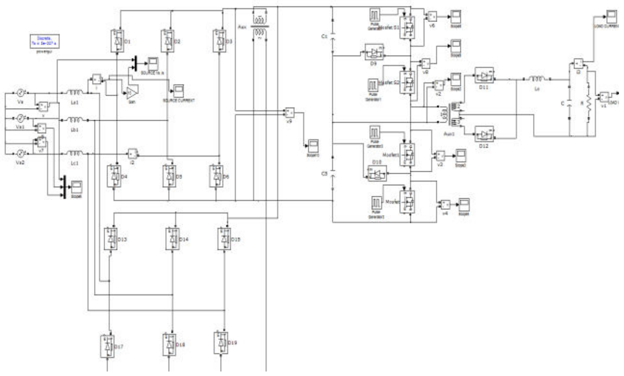


Fig.6 Matlab/Simulink Model of Proposed Converter.

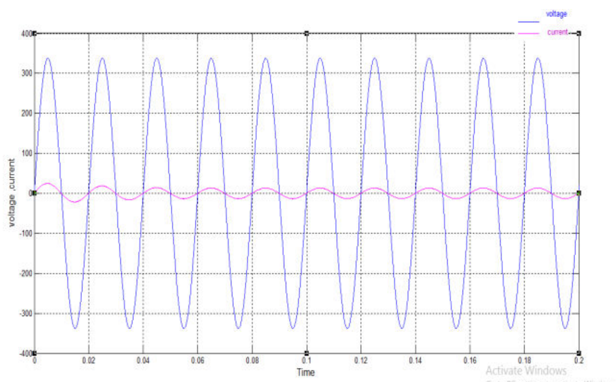


Fig.7 Simulated Input Wave Form of The Voltage And Current Of The Proposed Converter.

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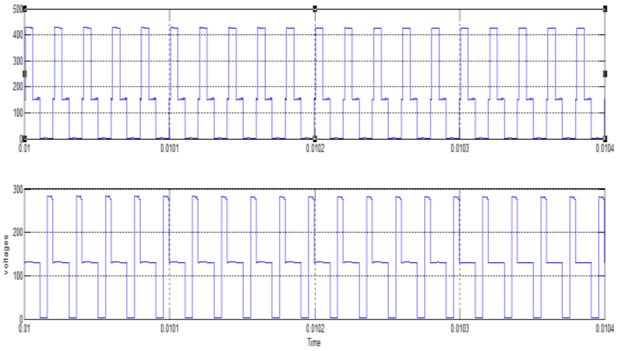

Fig.8 Simulated Top Switch Voltages Vds1 and Vds2.

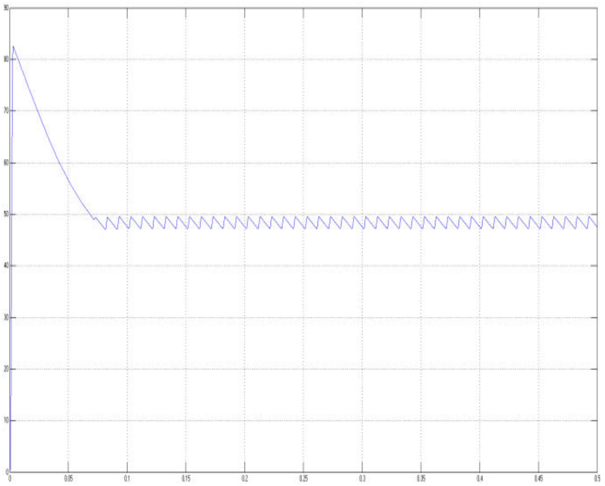

Fig.9 Simulated Output Wave form of The Converter of The Proposed Converter.

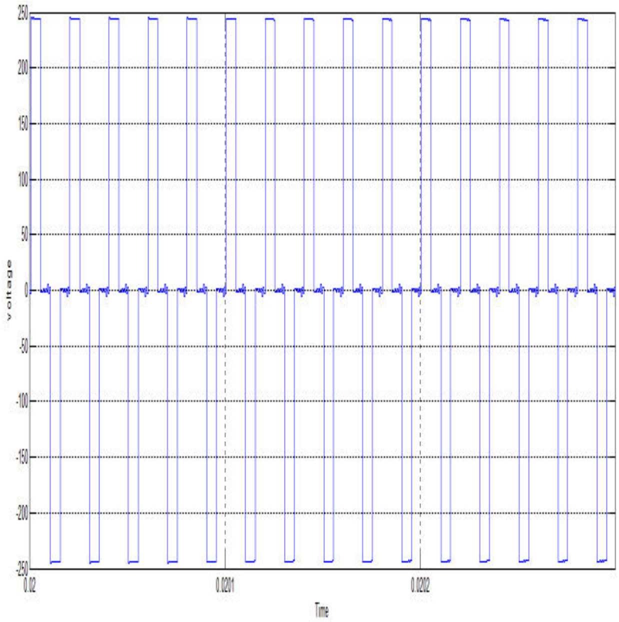

Fig.10. Simulated output wave form of the voltage at primary winding of the transformer of the proposed converter.

Case 2: Design of Closed -Loop Circuit of Proposed AC-DC Converter

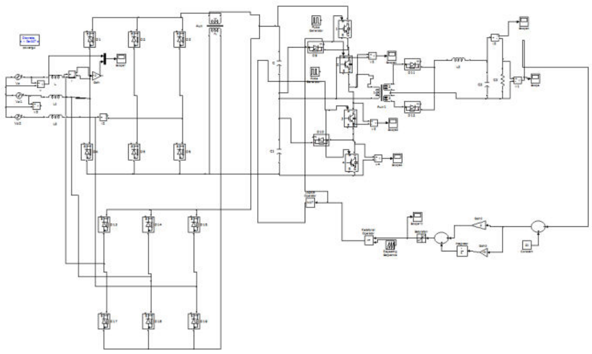

Fig.11. Matlab/Simulink Model of Proposed Converter Operated under Closed Loop Manner.

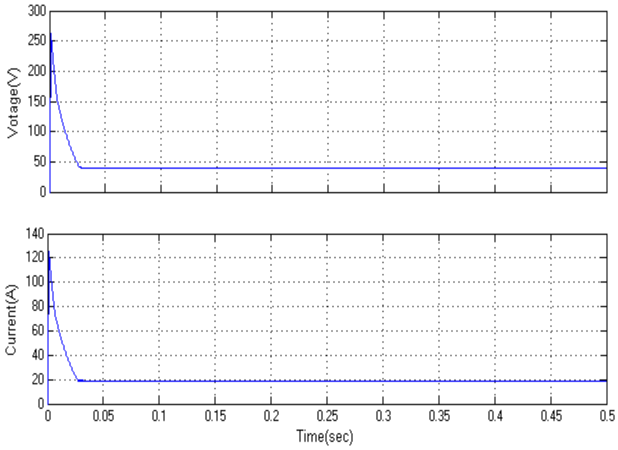

Fig.12. Output Voltage & Current of Proposed Converter Operated under Closed Loop Manner.

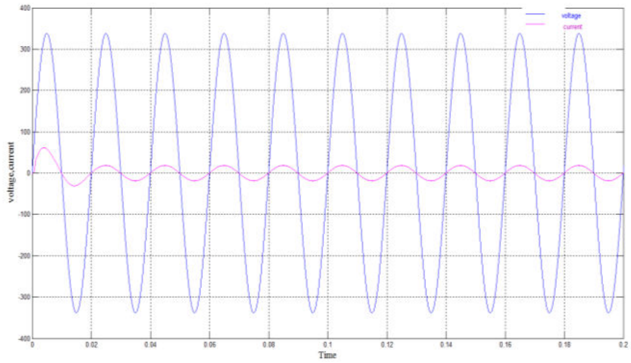

Fig.13. Simulated input wave form of the Voltage and current of the closed loop of proposed converter.

Fig.13. Source Side Voltage & Current – in Phase Condition, depicts the unity power factor at source side, with low THD response and maintain qualitated power at utility side, as per IE standards

VI. CONCLUSION

Numerous industrial applications have begun to require higher power apparatus in recent years. Power-electronic converters are becoming popular for various industrial applications. In this concept a new three level AC to DC converter for closed loop control logic for updating the performance of the dc drive and also a new three-phase three-level single-stage power-factor corrected ac–dc converter with interleaved input has been proposed in this paper. The converter can operate with lower peak voltage stresses across the switches and the DC bus capacitors as it is a three-level converter. This converter provides variable output voltage with improved power factor. The all simulation results are verified through Matlab/simulink software.

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