Design of Power factor Correction Based Bridge-less Converter for Different Loads of SMPS

Dr. N. Samba Siva Rao
Professor
Department of Electrical & Electronics Engineering,
NRI Institute of Technology, Agiripalli; AP, India.

K. Chinnari Aparna
PG Scholar
Department of Electrical & Electronics Engineering,
NRI Institute of Technology, Agiripalli; AP, India.

Abstract– This paper proposes a power-factor-corrected canonical switching cell (CSC) converter-based switched-mode power supply for arc-welding applications. In the proposed system, CSC converter operating in discontinuous inductor current mode (DICM) is used to attain inherent power factor correction. The DICM operation substantially reduces the complexity of the control and effectively regulates the dc-link voltage. At the back end, a pulse width-modulated (PWM) isolated full bridge dc–dc converter is used to provide a high-frequency isolation, which is mandatory for the arc-welding process. A dual-loop control scheme is utilized to incorporate over current protection and to regulate dc voltage at the output making it suitable for arc-welding applications. Later the proposed converter is re modeled as bridgeless converter for better efficiency, less total harmonic distortion and multiple functionality of the system. Finally when compared two systems the bridgeless converter systems are having better power quality than conventional converters is observed.

Keywords—Arc Welding Power Supply (AWPS), Bridgeless, Power Quality, Total Harmonic Distortion (THD), CSC Converter.

I INTRODUCTION

Modern Arc Welding Power Supply (AWPS) employs controllable high frequency (HF) DC-DC power converter(s) with excellent dynamic and steady state performance compounded with stringent voltage-current regulation. Generally, robustness, portability and simplicity are amongst the prevailing design criteria [1] for the AWPS. Moreover, to ensure suitably systematized metal droplet transfer through the established arc, AWPS should limit the welding load current even during the short circuit condition and must operate satisfactorily over a very wide load range i.e. from rated load to short-circuit condition. Also, a broad span of controlled load current is essential to enhance the welding action. Thus, in order to control the welding characteristics, the output DC voltage along with the output DC current, must always be regulated [2].

Mainly the conventional switched mode power supplies (SMPSs) for welding applications comprise a front-end uncontrolled diode bridge rectifier (DBR) followed by a bulk DC-link capacitor [3]. The presence of the DBR generally leads to problems such as high conduction loss and increased harmonic currents thus creating interference in power and communication lines. In the past few years, bridgeless (BL) power factor corrected (PFC) converters have gained huge attention and popularity due to their higher efficiency. In an effort to improve the Power Quality (PQ) of the SMPSs, various BL boost converter based topologies have been reported in the literature [4] adhering to the stringent requirements put forth by the international PQ standard IEC 61000-3-2 [5].

A considerable amount of work on BL boost PFC converter has been carried out because of its low cost, simplicity and high performance in terms of efficiency and PF. Nonetheless, the BL boost PFC converter suffers from some major limitations such as high start-up inrush current, lack of current limiting during overload conditions and ineptness to step down the input voltage. However, these are some of the essential prerequisites in designing an SMPS for welding applications. A BL buck converter has a poor PFC capability and also does not support short-circuit operating conditions. Among various buck-boost converters, Cuk converter offers high quality input and output currents due to the presence of inductors at both input and output side of the converter [6]. Thus, considering a BL PFC Cuk converter that is capable of yielding lower voltage at the output would be a viable alternative.

The objective of this paper is to design and model a single phase AWPS using BL-Cuk converter at the front end and a PWM full-bridge (FB) DC-DC converter for high-frequency isolation at the load end. Its meritorious features include output voltage stability and short-circuit withstand capability. The BL -Cuk converter is designed to operate in Discontinuous Conduction Mode (DCM) to attain inherent PFC at the input AC mains [7-8]. Independent closed loop control functions are used in both stages. A Pulse Width Modulation (PWM) control strategy has been implemented with a constant switching frequency of 50 kHz. Its fast dynamic response during load variations leads to a better arc stability and uniform weld bead quality. The detailed analysis and design of the proposed AWPS are discussed in following sections to illustrate its improved performance in terms of unity

PF and reduced THD in the AC mains current at different loads and supply voltage conditions. The efficacy of the proposed improved PQ AWPS is demonstrated by means of simulation results using MATLAB/SIMULINK tool.

II PROPOSED CSC CONVERTER BASED AWPS

In this project, a CSC converter is proposed as a front converter to deal with the PQ issues associated with an AWPS. Moreover, an effort has been put forward to incorporate over current withstand capability in the proposed AWPS, which is very important for achieving high-quality weld. CSC converter allows one to overcome the shortcomings of aforementioned buck–boost converters by having less number of input devices, nonpulsating input current, etc. [23]–[26]. Additionally, the DICM operation results in inherent PFC and fast dc-link voltage regulation using a single-loop voltage feedback controller [27]. Besides, power switch is turned on at zero current and the freewheeling diode is turned off at zero current reducing the switching losses. The CSC converter is followed by full-bridge (FB) converters, which provide high-frequency isolation desired for safe welding operation [28], [29]. The FB converters are used to emulate the conventional welding power supply. Three FB converter modules are connected in parallel to incorporate the power expandability feature depending on the current rating of the power supply. The major contribution of this paper is twofold: 1) input PQ improvement by using CSC converter at the front end, and2) voltage regulation and over current limiting at the output end by using FB converters. The AWPSs that are currently available in the market are devoid of power factor correction and input PQ improvement. AWPS stands out as a special entity as compared.

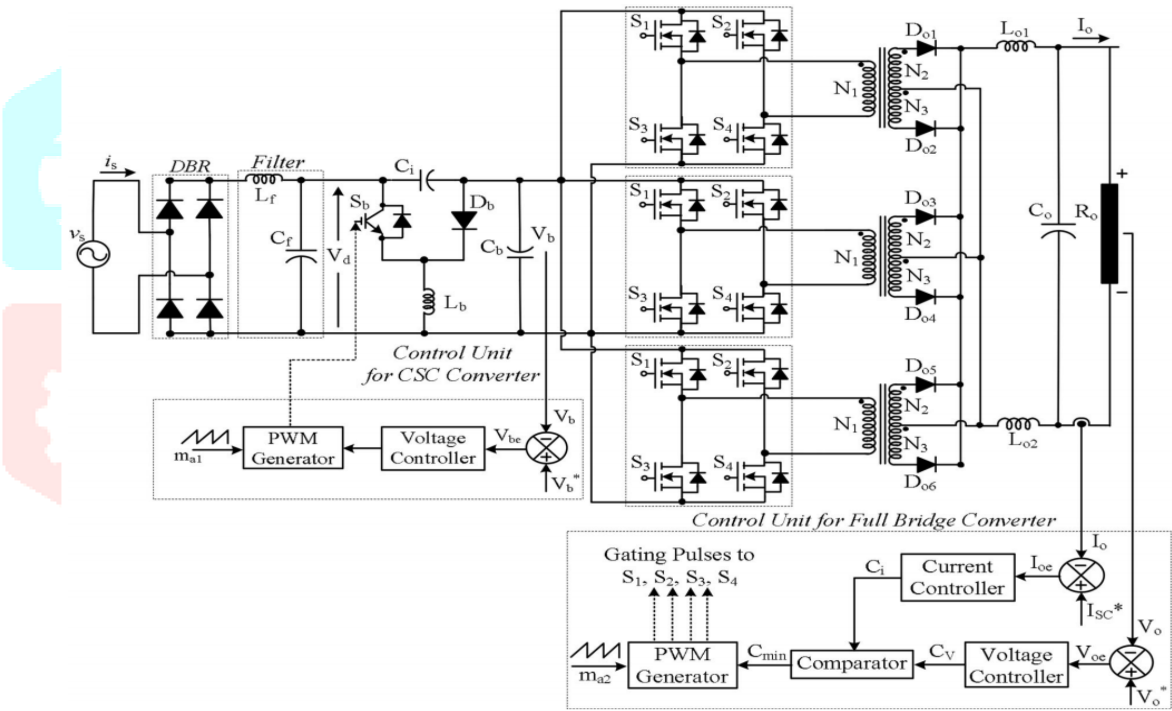
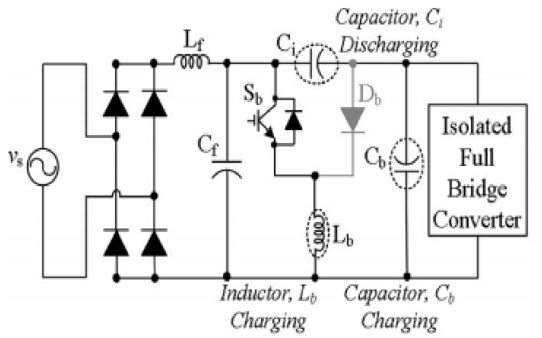
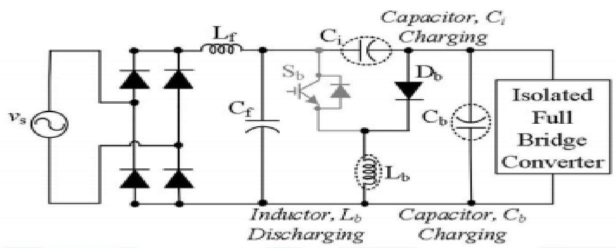


Fig 1 Schematic of BL Cuk converter and isolated FB converter based AWPS

The system configuration of the proposed PF-corrected AWPS is presented in Fig.1. In this section, the DBR is followed by CSC converter, which acts as a pre regulator to achieve PFC at the utility interface. The DICM operation of the CSC converter minimizes the turn-on switching losses of the power switches and enhances the reverse recovery of the output diodes significantly. The CSC converter converts the rectified input ac mains voltage into an intermediate regulated dc voltage. The controlled output of the CSC converter is fed to the FB converters, which provide the desired dc arc voltage suitable for the welding load. The FB converters are designed to operate in continuous conduction mode (CCM). The proposed topology is designed taking into account the important properties of arc welding process like constant output dc voltage, output dc arc current regulation during overload, and reduced input current harmonics over wide line/load range. Individual control loops are designed for both the converters (CSC and FB) to optimize their functions. The efficient control of AWPS facilitates fast dynamic response, which enables to achieve high-quality weld.



(a)



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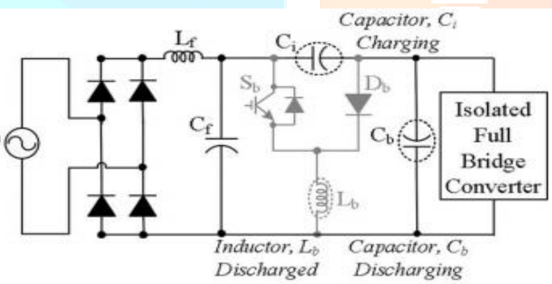

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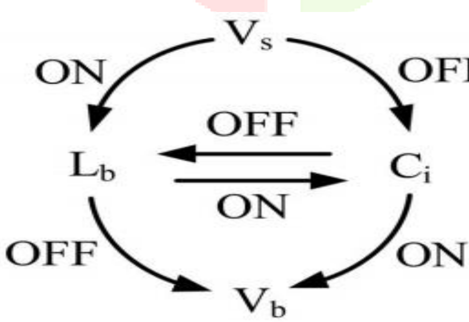
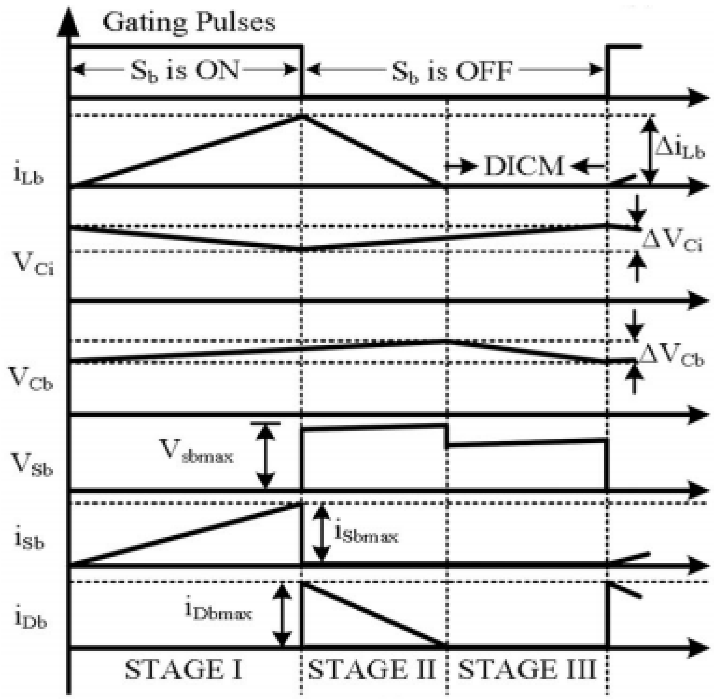


(d)



(e)

Fig.2. Operation of CSC converter: (a) Stage I, (b) Stage II, (c) Stage III, (d) energy transfer in one switching period, and (e) waveforms during one switching period.

III. OPERATION OF PROPOSED CSC CONVERTER-BASED AWPS

The operating principle of both the converters is discussed in detail. The following assumptions are made to simplify the analysis of the proposed AWPS:

1) all semiconductor devices are considered to be ideal;

2) all semiconductor devices are considered to be ideal;

3) the capacitors Cb and Co are considered to be large enough to maintain the output voltages Vb and Vo as constants without any ripple during one switching period;

4) the supply voltage vs is considered to be a constant during one switching frequency (fs) cycle as fs >> f, the line frequency.

Operating Modes of CSC Converter

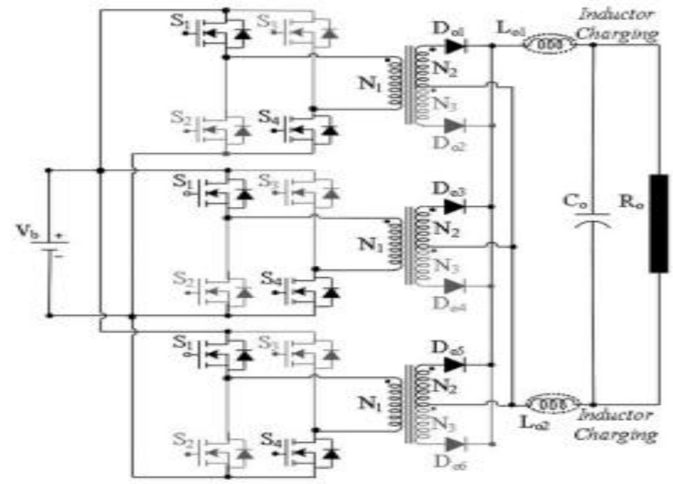
The operating principle of the CSC converter is analogous to the conventional Cuk converter although Cuk converter uses two inductors in place of a single inductor for the CSC converter. The operation of CSC converter is presented in Fig.2. The rectified output of the DBR is given to the CSC converter. For DICM operation, there are three intermediate operating stages of the CSC converter for every switching cycle, which are described as follows:

Stage I: During this stage, the switch Sb conducts while the diode Db is reverse biased as shown in Fig 2(a). In this interval, the power is transferred from the supply as well as from the intermediate capacitor Ci to the inductor Lb as presented in Fig 2(d). Therefore the intermediate capacitor Ci discharges through the inductor Lb and dc-link capacitor Cb causing the voltage across the intermediate capacitor to decrease. The value of intermediate capacitor Ci must be large enough to maintain its voltage continuous during this period.

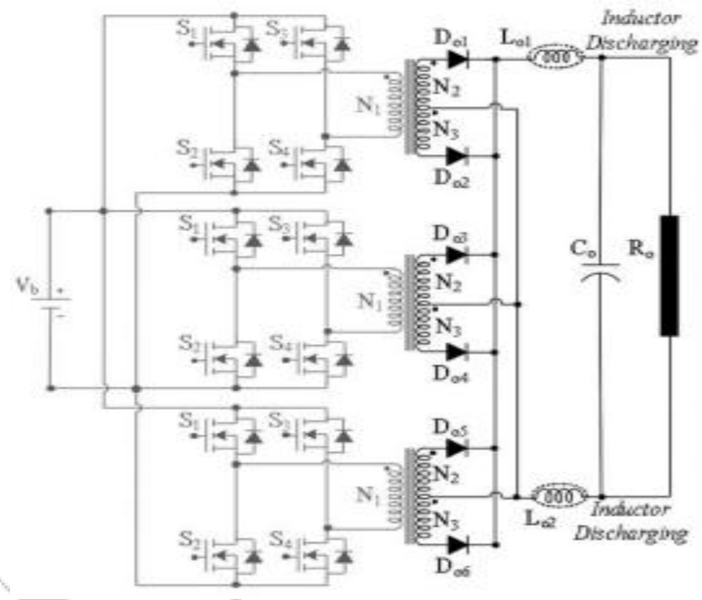
Stage II: This stage begins when the switch is turned off leading to the conduction of diode Db. As shown in Fig.2(b),the energy stored in inductor Lb is released to intermediate capacitor Ci and dc-link capacitor Cb. Thus, the current through the inductor Lb starts decreasing while the voltage across the intermediate capacitor Ci begins to increase. The voltage across the dc-link capacitor Vb also continues to increase.

Stage III: This stage is illustrated in Fig. 2(c). When the current through the inductor Lb becomes zero, the converter enters

into DICM as shown in Fig 2(e). The intermediate capacitor Ci continues to get charged from the supply. As the diode is reversing biased, Ib is provided by discharging of the dc-link capacitor Cb. Hence, the dc-link voltage decreases during this period. The energy transfer process for CSC converter during one completes witching period is shown in Fig 2(d). The current through the inductor Lb remains zero until switch Sb is triggered again to restart the switching cycle as shown in Fig. 2(e).



(a)



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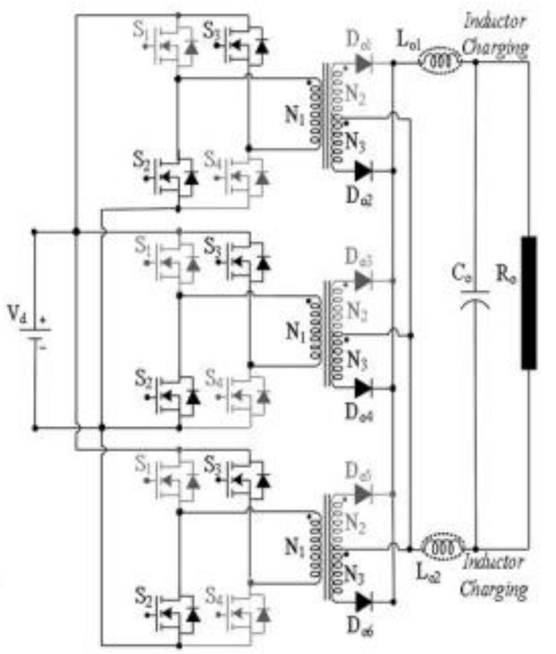

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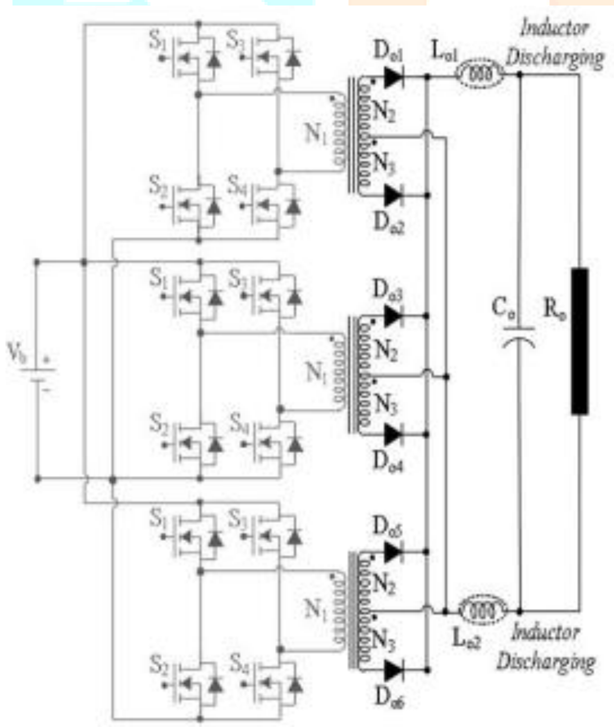

(d)

Fig.3. Operation of FB buck converter: (a) Stage I, (b) Stage II, (c) Stage III, and (d) Stage IV.

Operating Modes of FB Converter

The controlled output of CSC converter is fed to the FB buck converter to step down the dc-link voltage to the desired level. Three FB converters are connected in parallel so that device rating can be reduced and also scaling up the power rating is easy. Referring to Fig 3, the FB converters operate in CCM whose operating stages are described as follows:

Stage I: This stage is initiated when the switches S1 and S4are turned on and the dc-link voltage Vb is applied across the primary winding of the high-frequency transformers (HFTs) as shown in Fig. 3(a). The diodes Do1, Do3, and Do5 become forward biased, and the energy is stored in the output inductorsLo1 and Lo2. This results in an increased inductor current while the output filter capacitor Co discharges through the welding load.

Stage II: During this stage, S1, S2, S3, and S4 are switched off while all the output diodes (Do1,Do2,Do3,Do4,Do5, and Do6) freewheel the energy stored in the output inductors Lo1 and Lo2. This stage is presented in Fig. 3(b). The inductors release its stored energy to the output capacitor Co and welding load; thus, the output inductor current starts decreasing linearly.

Stage III: Analogous to Stage I, switch pair S2 and S3 conducts to transfer the energy to output inductors, as shown inFig.3(c). Diodes Do1, Do3, and Do5 remain open during this interval. However, the output capacitor Co discharges through the welding load.

Stage IV: Likewise, Stages II and IV are similar, as shown in Fig.3(d), as none of the switch pairs conduct, and again the output rectifier diodes (Do1,Do2,Do3,Do4,Do5, and Do6) act as freewheeling diodes. The output inductors release their stored energy charging the output capacitor Co. This stage terminates when the switches S1 and S4 are switched on again and the operating modes repeat in each switching cycle.

IV.SWITCHING MODE POWER SUPPLY (SMPS)

In recent years, the switching mode power supply (SMPS) system have been achieved the high power density and high performances by developed power semiconductor devices such as; IGBT, MOS-FET and SiC. However, using the switching power semiconductor in the SMPS system, the problem of the switching loss and EMI/RFI noises have been closed up. This course produced the EMC limitation like the International Special Committee on Radio Interference (CISPR) and the harmonics limitation like the International Electro-technical Commission (IEC). For keeping up with the limitation, the SMPS system must add its system to the noise filter and the metal and magnetic component shield for the EMI/RFI noises and to the PFC converter circuit and the large input filter for the input harmonic current. On the other hand, the power semiconductor device technology development can achieve the high frequency switching operation in the SMPS technical area. The increase of the switching losses has been occurred by this high frequency switching operation. For this solution, the soft switching technique have been attracted the great interest in recent years. Using LC resonant phenomenon, this technique can minimize the switching power losses of the power semiconductor devices, and reduce their electrical dynamic and peak stresses.

Switched mode power supplies (SMPSs) are used for powering up different parts in a personal computer (PC) by developing multiple dc voltages from a single-phase ac voltage from the power grid. Normally, a diode bridge rectifier (DBR) followed by a filter capacitor is used at the front end of these SMPSs.

Configuration of Bridgeless-Converter-Based Multiple-Output SMPS

The proposed bridgeless-converter-based multiple-output SMPS consists of a single-phase ac supply feeding two back to-back-connected buck–boost converters with a half-bridge VSI and multiple-output HFT at the load end. The buck–boost converters are controlled suitably to obtain a high PF and low input current THD. The half-bridge VSI at the output takes care of high-frequency isolation with multiple dc output voltages being regulated. The operation of both converters in one switching cycle is described in the following subsections.

V MATLAB/SIMULINK RESULTS

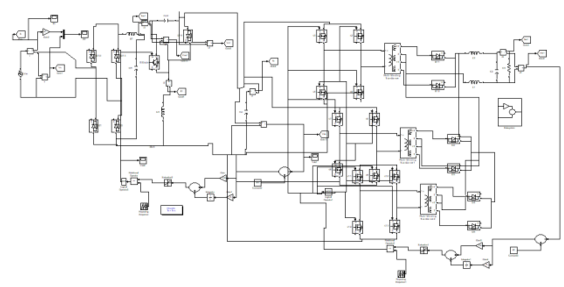

Fig 4 Simulation model of CSC converter and isolated FB converter based AWPS

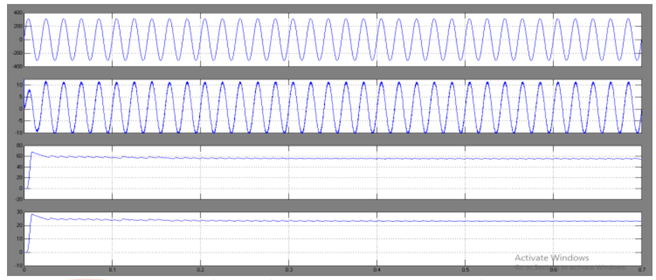

Fig 5 Simulation waveform of Steady state behavior of proposed converter at rated load and 220V (rms) supply voltage, source voltage, source current, output voltage and output current.

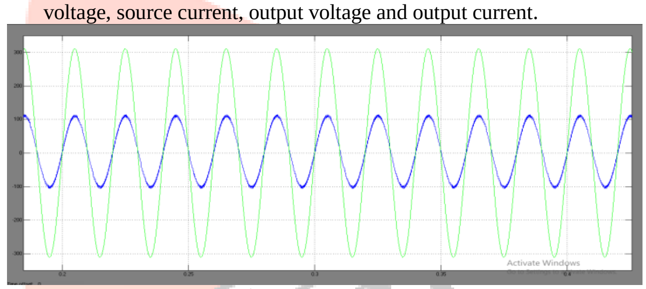

Fig 6 Simulation waveform of Input voltage and current

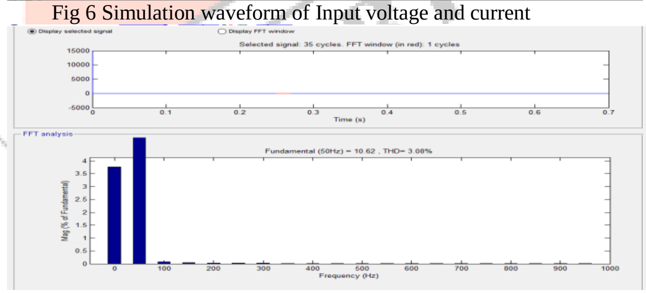

Fig 7 THD of source current with CSC converter

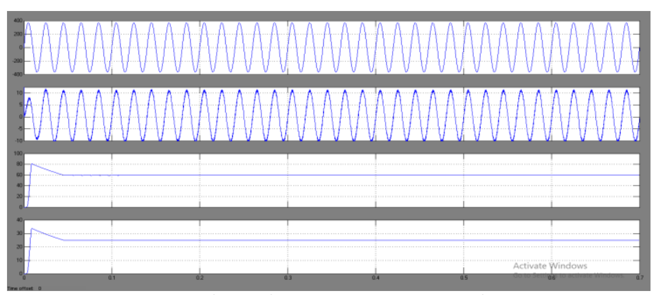

Fig 8 Simulation waveform of Steady state behavior of proposed converter at rated load and 260V (rms) supply voltage, source voltage, source current, output voltage and output current.

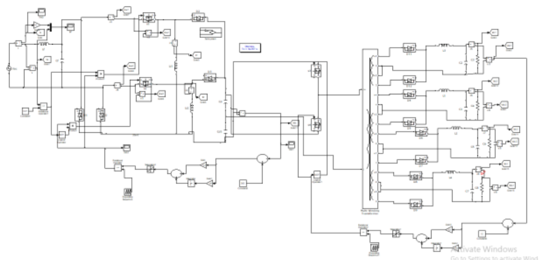

Fig 9 Simulation model of BL converter and isolated FB converter based SMPS

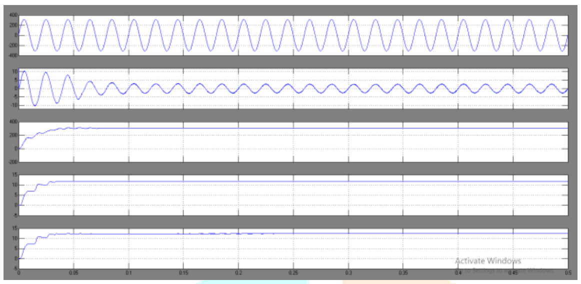

Fig 10 Simulation waveform of Steady state behavior of proposed converter at rated load and 220V (rms) supply voltage, source voltage, source current, output voltage and output current.

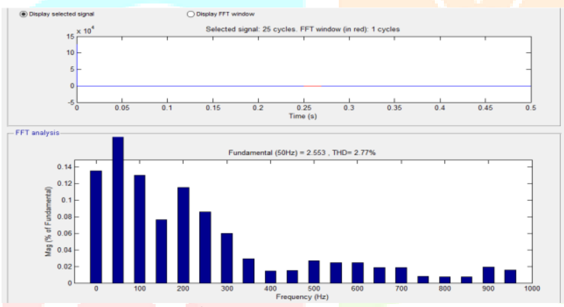

Fig 11 THD of source current with BL converter

VI CONCLUSION

The proposed circuit topology is a good solution as it offers excellent PFC features at the front end while the FB converter provides output isolation along with the over-current and startup protection. The component count has also reduced by integrating two power conversion stages. The quality of weld is enhanced by controlling the output side parameters to regulate the heat and mass input to the weld pool. Furthermore, it can be inferred from the obtained results that the proposed BL converter based system has provided robustness and fast response. It is evident from the obtained results that the THD of the AC mains current is well below 5%. The PF has also remained close to unity making it suitable for wide-range of line/load operations. In all, it can be concluded that the proposed BL converter based topology conforms to the requirements of the SMPS and THD less than the CSC converter.

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