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Design And Analysis of AC-DC Interleaved Negative Output Cuk Converter for Power Quality Enhancement

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***Abstract*:- This paper presents the analysis and design of a AC-DC Interleaved negative output Cuk converter for the enhancement of power quality in terms of improved power factor and less source current Total Harmonic Distortion (THD). This proposed converter can be used for all kind of AC-DC applications operating under the universal supply voltage of 90 V-260 V. This converter either operates in Continuous Conduction Mode (CCM) or Discontinuous Conduction Mode (DCM). The proposed work focuses on a power factor corrected negative output CUK converter operating in DCM of inductor current improves the power factor at AC mains nearly to unity and thereby reducing the THD under the prescribed limits of IEEE and IEC standards. The performance of the proposed converter is analysed using MATLAB/Simulink.**

Keywords:- Discontinuous Conduction Mode, Total Harmonic Distortion, Power Factor Correction, Power quality, Luo converter

I. INTRODUCTION

Traditionally Solid-state AC-DC converters are designed using diodes and thyristors to provide controlled and uncontrolled DC power. They have the problems of injected current harmonics, resultant voltage distortion, poor power factor at input AC mains, slowly varying rippled DC output at load end, low efficiency and require large size of AC and DC filters [1]. In view of stringent requirements of power quality at the input AC mains and their increased applications, a new breed of converters have been developed using Solid-state self-commutating devices such as MOSFET ,IGBT, GTO, etc. Such converters are classified as Boost, Buck, Buck-Boost AC-DC converters and are referred to as improved power quality converters. IPQC technology has matured at a reasonable level for AC-DC conversion with reduced harmonic currents, high power factor, low Electro Magnetic Interference (EMI) and Radio Frequency Interference (RFI) at input AC mains and well regulated good quality DC output to feed loads ranging from fraction of kW to MW power ratings.

Bhim Singh, Brij N. Singh, Ambrish Chandra, Kamal Al-Haddad. Asish Pandey, Dwarka P.Kothari (2003), [4] made a review of single phase improved power quality AC/DC converters. IPQC's can be considered to be a better alternative for high power quality improvement because of the reduced size of overall converter and its higher efficiency.

Sanjeev Singh and Bhim Singh (2012) [2] proposed a voltage controlled PFC Cuk converter based PMBLDCM drive for air conditioners. THD of the proposed converter is measured as 2.22% and PF is 0.9998. Bhim Singh and Ganesh Dutt (2007) proposed the analysis, design, modeling and development of single-switch AC/DC Converters for power factor and efficiency improvement. It has been found experimentally that zeta converter has 4% THD for DCM operation. Vashist Singh and Bhim Singh (2015) [3] explains the proposed converter with a single voltage sensor for DC link voltage control as compared to other two configurations, which reduces the cost of the overall system and hence it is used for low power applications. An improved power quality with Unity Power Factor (UPF) is obtained.

Mohammed Mahdavi and Hosein Farazanehfard (2011) [6] proposed a simplified control circuit where a current loop is not required. The converter is designed to operate in DCM. SEPIC converter is used to eliminate the requirement of passive filter. The harmonics are below the IEC 51000-3-2 standard. Jae-Won-Yang and Hyun-Lark DO (2013) proposed a brushless SEPIC converter with bridgeless topology, where the conduction losses are reduced. In order to eliminate the need of large inductor, an auxiliary small inductor and a capacitor is utilized to reduce the input current ripple. PF is 0.995. Vashist Bist and Bhim singh (2014) [8] proposed a converter which operates in DCM to provide an inherent PFC at the AC mains. The proposed bridgeless buck-boost converter uses a variable DC link voltage of VSI for improved power quality. THD of the proposed converter is 3.85% at rated condition with UPF.

This paper describes about the open loop and closed loop analysis of AC-DC Interleaved negative output CUK converter with a PI controller. The organization of the proposed work is as follows: Circuit configuration is described in section 2. Section 3 presents the design of the proposed converter. Open loop and closed loop results and discussions of the developed software model is demonstrated in section 4. The summary, concluding marks and recommendations for future improvement are given in section 5.

II. CIRCUIT CONFIGURATION

The circuit configuration of the proposed AC-DC converter is shown in figure 1. It operates in a universal supply voltage of 90 V- 260 V. The input filter is required to reduce the ripple in the input current and power factor correction. The power circuit strategy is presented with three inductors, three capacitors, five diodes and one MOSFET switch operating at a switching frequency of 10 kHz.

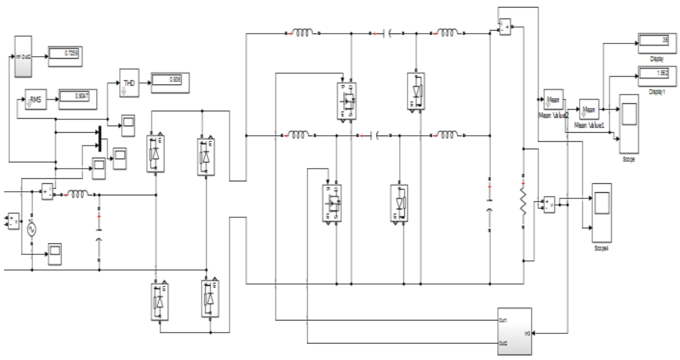

Figure 1. AC-DC Interleaved negative output CUK converter

The proposed converter is designed for 100W applications. The regulated output voltage and output current will be 48 V and 2.083 A respectively.

III. DESIGN OF AC – DC INTERLEAVED NEGATIVE OUTPUT CUK CONVERTER

The design specifications of the proposed converter are shown in

TABLE – I

TABLE – I DESIGN SPECIFICATION OF THE CONVERTER

PARAMETERS	VALUES
Supply Voltage (V_{in})	90 V– 260 V
Filter Inductor (L_f)	100 mH
Filter Capacitor (C_f)	2000 µF
Input Inductor (L_1)	470 µH
Intermediate Capacitor (C_1)	2.2 µF
Output Inductor (L_0)	1200 µH
DC Link Capacitor (C_0)	2200 µF
Output Power (P_0)	100 W
Output Voltage (V_0)	48 V
Switching Frequency (f_s)	10 KHz

IV. RESULTS AND DISCUSSIONS

The AC-DC Interleaved negative output CUK converter is simulated in MATLAB/Simulink.

4.1 Open loop Simulation of AC-DC Interleaved negative output CUK converter

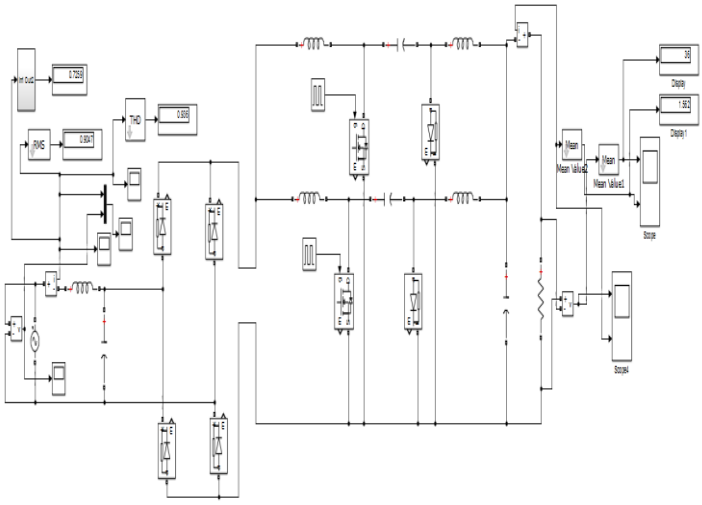

Figure 2. Open loop simulation of AC-DC Interleaved negative output CUK converter

Figure 2 shows the open loop simulation diagram of the proposed converter. In this, to demonstrate the importance of supply side filter, two different analyses are carried out.

Figure 3 shows the output voltage waveform of the AC-DC Interleaved negative output CUK converter under open loop control without filter. The desired output voltage of -48 V is not obtained in open loop control; instead we obtained an output voltage of -50.5 V.

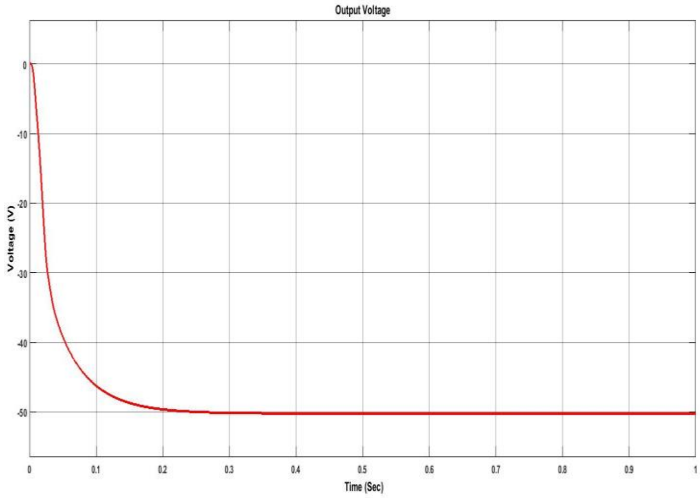

Figure 3. Output Voltage of open loop simulation of AC-DC Interleaved negative output CUK converter

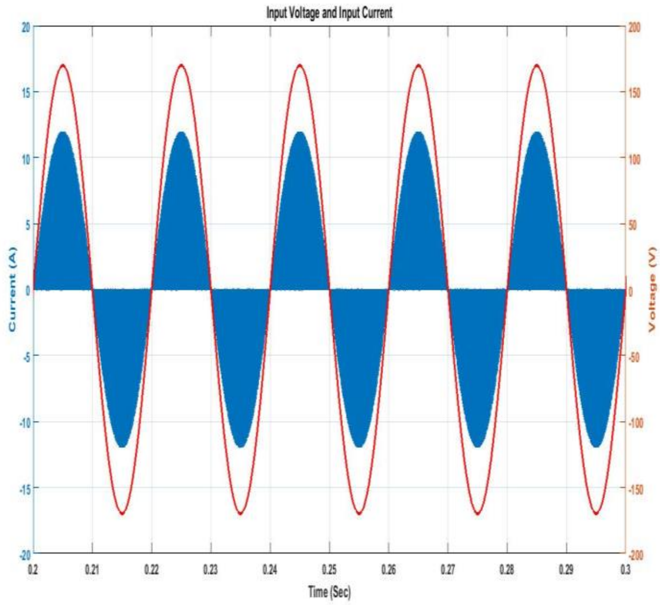

Figure 4. Supply current and supply voltage without filter

Figure 4 & 5 shows the source voltage, distorted source current waveform and its corresponding FFT analysis respectively. It shows that, in the absence of LC filter, there is an injection of a very high amount of harmonic content in the source current, which is not under the permissible limits of IEEE standard. Its THD is around 226%. Also it exhibits a very poor power factor of 0.35.

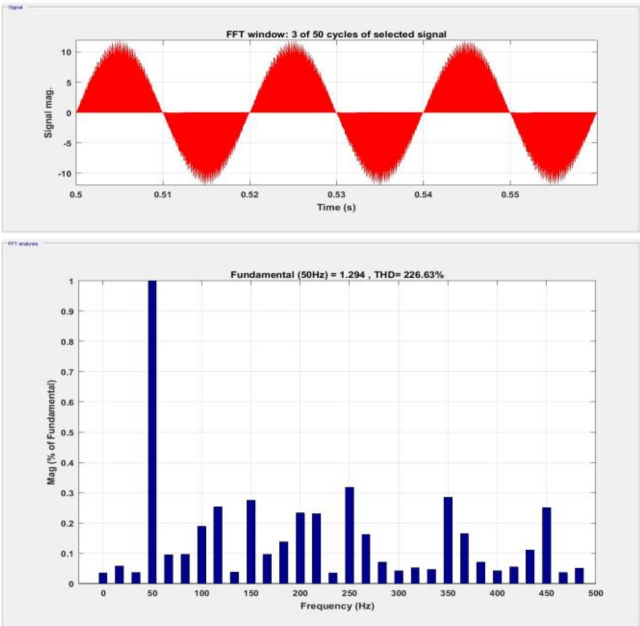

Figure 5. THD of supply current without filter

Figure 6 shows the output voltage waveform of the AC-DC Interleaved negative output CUK converter under open loop control with filter. The desired output voltage of 48 V is not obtained in open loop control; instead we obtained an output voltage of 51.5 V under rated conditions.

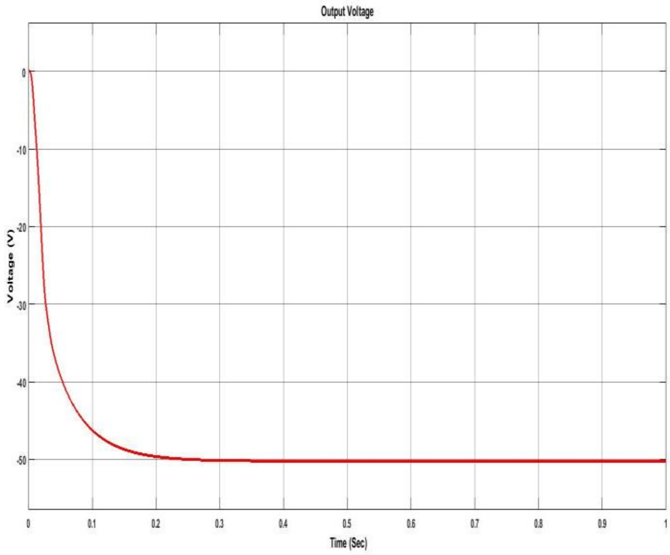

Figure 6. Output Voltage of open loop simulation of AC-DC Interleaved negative output CUK converter

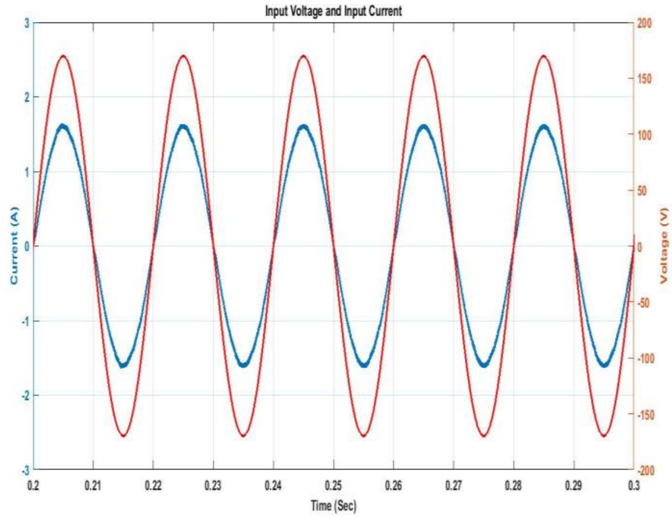

Figure 7. Supply current and supply voltage with filter

Figure 7 & 8 shows the source voltage, source current waveform and its corresponding FFT analysis. It shows that, in the presence of LC filter, the injection of harmonic content in the source current is very low, which is under the permissible limits of IEEE standard. Also, as the voltage and current are in-phase with each other, it leads to a near unity power factor.

4.2 Closed loop Simulation of negative output AC-DC Interleaved Luo converter using PI controller.

The PI controller is the most commonly used in closed loop systems because of its performance in terms of simplicity. It produces an error signal by comparing the desired output signal with the actual output signal. Figure 9 shows the closed loop simulation diagram of the proposed converter.

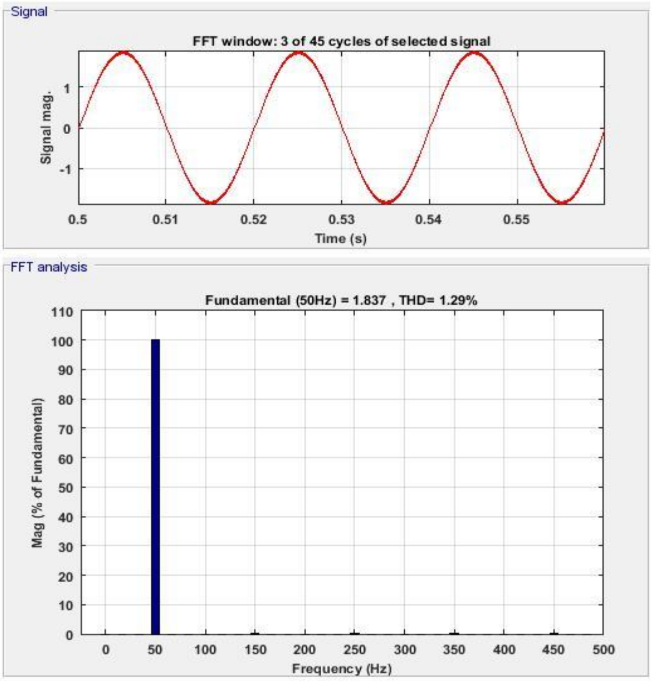

Figure 8. THD of supply current with filter

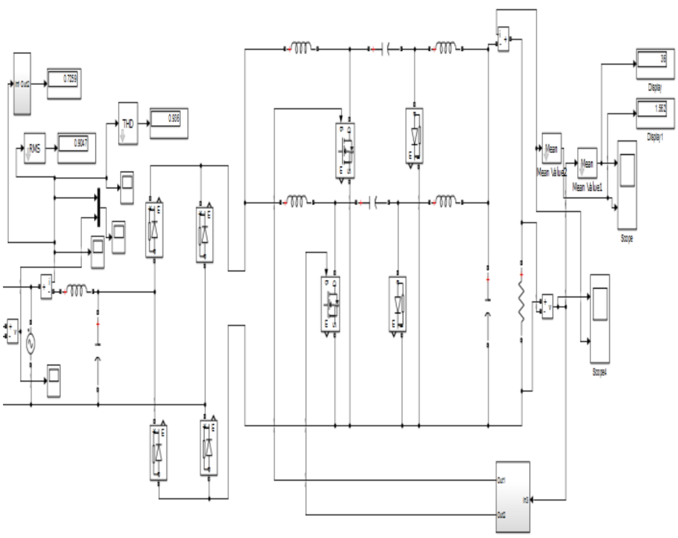
Figure 9. Closed loop simulation of AC-DC Interleaved negative output CUK converter

Figure 10 shows the output voltage waveform of the AC-DC Interleaved negative output CUK converter under closed loop control. The desired output voltage of 48 V is obtained in this type of control; which is attained at a time t=0.6 second. Also it is inferred from the waveform that, the voltage ripples is also very less.

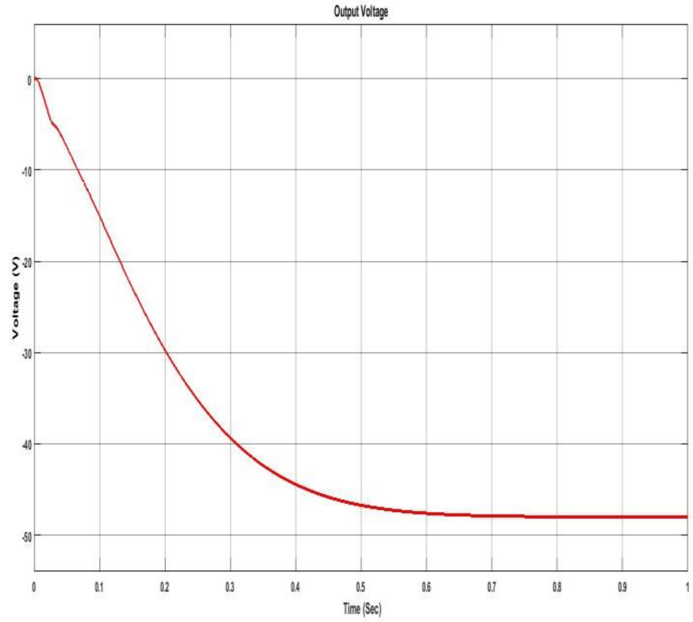

Figure 10. Output Voltage of closed loop simulation of AC-DC Interleaved negative output CUK converter

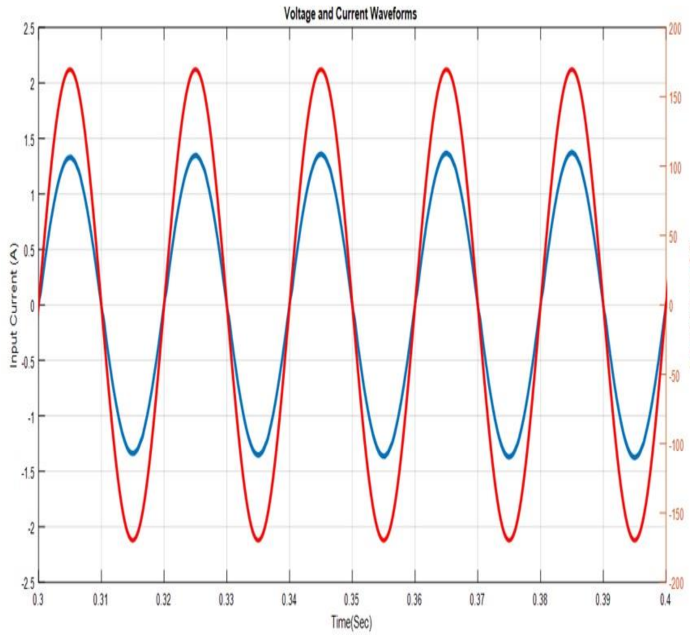

Figure 11. Supply current and supply voltage

Figure 11 & 12 shows the source voltage, source current waveform and its corresponding FFT analysis. It shows that, in the presence of LC filter, the injection of harmonic content in the source current is very low, which is under the permissible limits of IEEE standard. As, the voltage and current are in-phase with each other, it leads to a near unity power factor. The corresponding THD value is found to be 1.42% which is very less.

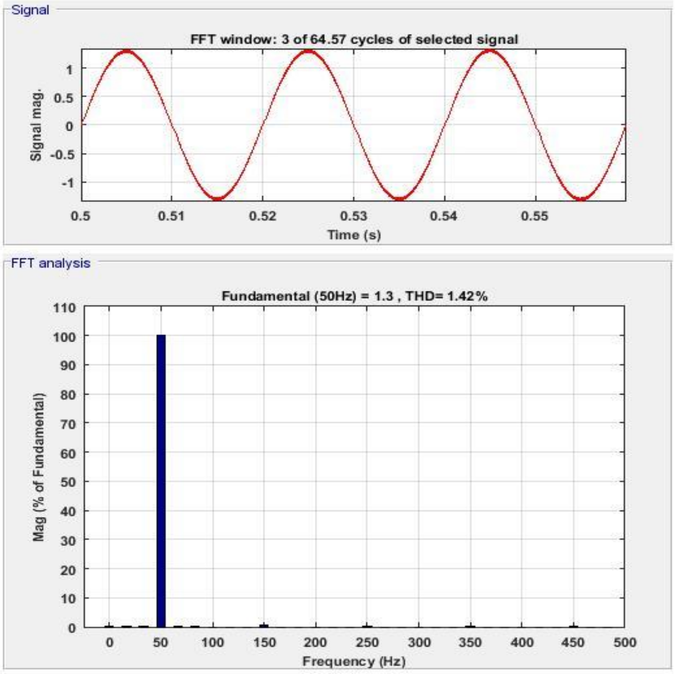

Figure 12. THD of supply current

TABLE – II
PERFORMANCE ANALYSIS OF AC-DC INTERLEAVED NEGATIVE OUTPUT CUK WITH PI CONTROLLER BY VARYING SUPPLY VOLTAGE

Input Voltage (V)	V_o (V)	I_o (A)	I_s (A)	THD (%)	Power Factor	Efficiency
90	48	2.083	1.25	1.42	0.9901	85.92%
120	48	2.083	0.93	2.41	0.9885	85.5%
150	48	2.083	0.75	2.55	0.9881	85.21%
180	48	2.083	0.63	2.76	0.9870	84.48%
210	48	2.083	0.55	3	0.9840	83.57%
230	48	2.083	0.50	3.21	0.9825	82.84%
260	48	2.083	0.45	3.56	0.98	81.6%

TABLE – III
PERFORMANCE ANALYSIS OF AC-DC INTERLEAVED NEGATIVE OUTPUT CUK CONVERTER WITH PI CONTROLLER BY VARYING LOAD WITH V_{IN} = 120 V

% Load	V_o (V)	I_o (A)	I_s (A)	THD (%)	Power Factor	Efficiency
100	48	2.083	0.93	1.42	0.9901	85.92%
80	48	1.666	0.75	2.41	0.9850	85.5%
60	48	1.249	0.56	2.55	0.9801	85.21%
40	48	0.835	0.39	2.76	0.9770	84.48%
20	48	0.421	0.21	3	0.9740	83.57%

TABLE – IV
PERFORMANCE ANALYSIS OF AC-DC INTERLEAVED NEGATIVE OUTPUT CUK CONVERTER WITH PI CONTROLLER BY VARYING LOAD WITH V_{IN} = 230 V

% Load	V_o (V)	I_o (A)	I_s (A)	THD (%)	Power Factor	Efficiency
100	48	2.083	0.50	2.21	0.9845	82.84%
80	48	1.666	0.41	2.51	0.9805	82.38%
60	48	1.249	0.32	3	0.9750	81.35%
40	48	0.835	0.23	3.9	0.9720	78%
20	48	0.421	0.13	4.9	0.9687	73%

TABLE – V
PERFORMANCE ANALYSIS OF AC-DC INTERLEAVED NEGATIVE OUTPUT CUK CONVERTER WITH PI CONTROLLER BY VARYING REFERENCE VOLTAGE WITH V_{IN} = 120 V

Ref. Voltage (V)	I_o (A)	I_s (A)	THD (%)	Power Factor	Efficiency
48	2.083	0.931	1.42	0.9901	85.5%
40	1.736	0.662	3	0.9885	84.83%
32	1.389	0.424	3.21	0.9881	83.47%
24	1.042	0.248	3.56	0.9870	82.74%

TABLE – VI
PERFORMANCE ANALYSIS OF AC-DC INTERLEAVED NEGATIVE OUTPUT CUK CONVERTER WITH PI CONTROLLER BY VARYING REFERENCE VOLTAGE WITH V_{IN} = 230 V

Ref. Voltage (V)	I_o (A)	I_s (A)	THD (%)	Power Factor	Efficiency
48	2.083	0.504	2.21	0.9715	82.84%
40	1.736	0.362	2.76	0.9645	81.7%
32	1.389	0.245	3.74	0.9520	80.48%
24	1.042	0.155	4.5	0.9105	74.14%

V. CONCLUSION

In this paper, the design and simulation of AC-DC Interleaved negative output CUK converter have been carried out for 120V input and 230V output. Both open loop and closed loop analysis have been done for the designed converter. Power factor has also improved to nearly unity as input voltage and input current are in-phase to each other. In general the implementation of PI controller has reduced peak overshoot and THD with improved power factor.

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