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Modeling and Simulation of Input Switched AC-DC SEPIC Converter with PFC Control for Optimized Operation

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Abstract—A new configuration of single phase AC-DC SEPIC converter with PFC controller has been designed for achieving higher efficiency, power factor with lower THD as compared to conventional converters. The proposed bridgeless converter provides near unity power factor than conventional converters. The proposed converter utilizes a single switch with two diodes at the input side. Conventional converter suffers from lots of demerits such as high THD in input current, low power factor whereas newly designed converter significantly improves these parameters. Despite satisfactory results in open loop configuration, the PFC controller has been added to obtain more precise results. Results were obtained by using PSIM software.

Keywords—SEPIC Converter, Power Factor Correction, Total Harmonic Distortion

I. INTRODUCTION

Conventional AC-DC converters experience deteriorated performances due to distorted signals of input current. Several research works have been carried out to overcome this drawback. Traditional improvement methods consist of using rectifier with filter at the input side. To adapt this strategy, high valued inductor and capacitor are needed, which is practically burdensome[1]. Moreover, heat is generated in bridge rectifiers due to high forward voltage drop. Though lots of research have been conducted for the improvement of the power quality of the overall power system, most of the newly designed configurations are still suffering from low power factor with more THD in input current[2]. Proper design of PFC circuit can help in order to overcome such types of problems.

Active PFC avoids producing large harmonics in input current[3]–[5]. Dual switched boost rectifiers are preferable as they are inexpensive and simple alongside providing higher efficiency. Ref[6] analyzes the performance of this type of rectifier, although it suffers from some major drawbacks. PFC and SMPS circuits which are suitable for low-to-medium power range consists of front-end bridge rectifier, added with high frequency dc-dc converters. These converters can be different types as boost, buck-boost, CUK, SEPIC, flyback converter etc. Also, many bridgeless converters has been designed to improve the performance[7]–[10].

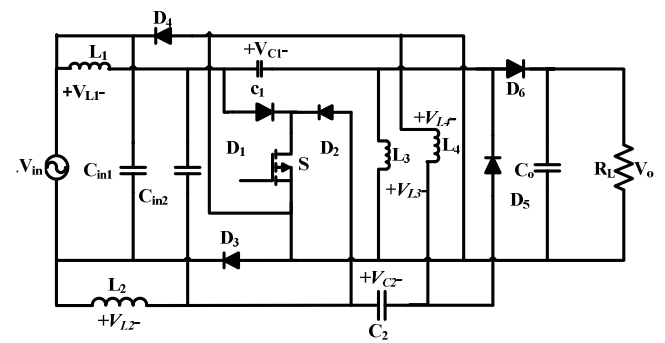
SEPIC AC-DC converter is a switched mode power supply converter which converts an AC signal to a high level

DC signal. Research works on this converter has recognized its contribution in the overall performance improvement[11]–[14]. This proposed work on SEPIC converter aims to achieve more precise results.

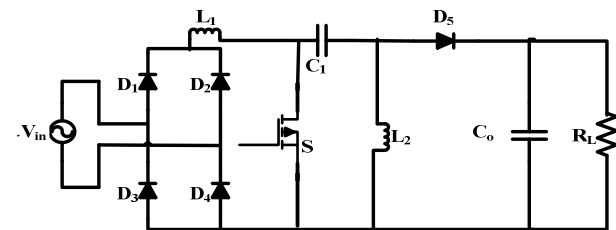
II. PROPOSED CONVERTER

A. SEPIC Converter

A SEPIC converter is analogous to a Buck-Boost converter, except it has favorable circumstances of producing output which is not inverted. The proposed converter shown in Fig. 1(a) uses series capacitor C_1 and C_2 to couple energy from the input side to the output side of the circuit. Instead of using bridge rectifier in the input side, two filter capacitors have been added to get distortion less input current whereas conventional converter uses bridge rectifier to rectify the input signal. The proposed circuit operates in a total of four modes for both negative and positive half



(a)



(b)

Fig. 1 SEPIC Converter (a) Proposed (b) Conventional

cycles of the sinusoidal input voltage. Although proposed circuit consists of more components than the conventional circuit, it performs better in all the measured aspects. The performance have been shown in the simulation part of the paper.

III. PRINCIPLE OF OPERATION

A. Single Phase Sepic Converter

The four stages of operation of the proposed SEPIC converter has been shown below:

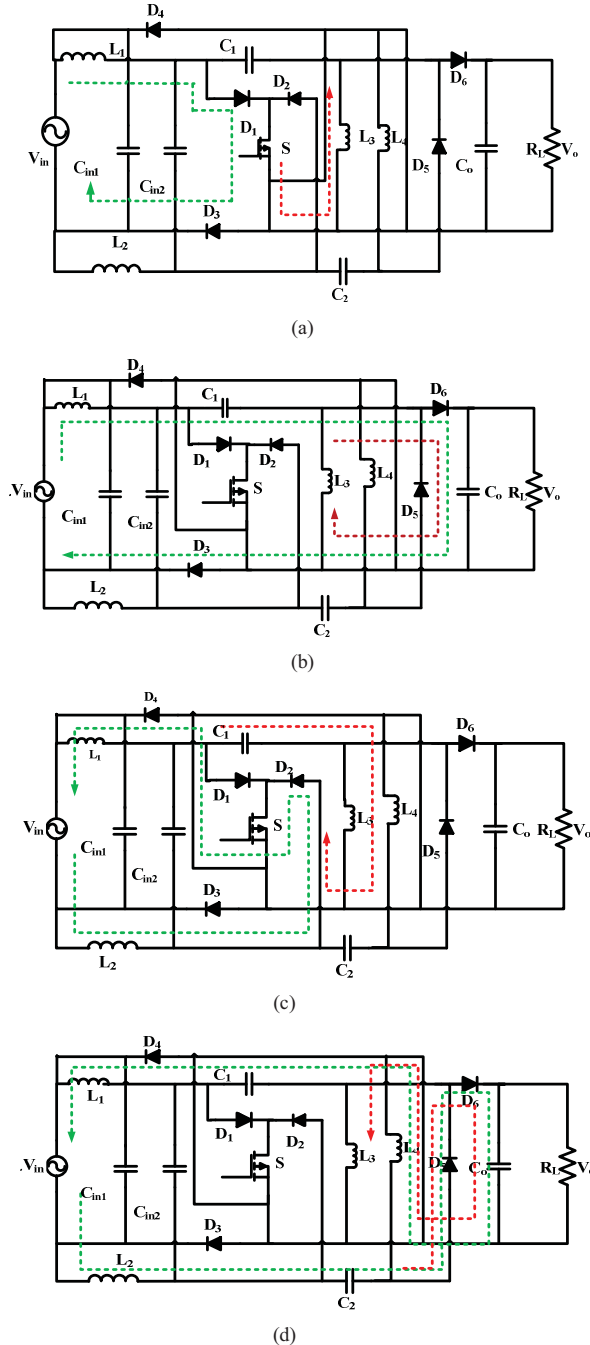


Fig. 2 Operational modes of proposed circuit (a) Mode 1 (b) Mode 2 (c) Mode 3 (d) Mode 4

In the ON state of switch S, when positive half cycle of the input signal is applied, current flows in two paths. As shown in Fig. 2(a), the first path starts from the input, flowing via inductor L_1 and through the switch S; whereas in the second path, capacitor C_1 and inductor L_3 will get charged. Diode D_6 is forward biased when it gets positive half cycle of the input signal in the OFF state of the switch. During this time, the current passes through two paths as given in Fig. 2(b). One path is from L_1 through the R_L and returns back to the output via diode D_6 . The other path of movement is along inductor L_3 and the diode D_6 . In the third mode of operation, switch S is turned ON amid the negative cycle of the supply while D_5 and D_6 operate in non-conducting mode. Current again streams in two ways, as appeared in Fig. 2(c). Again, when S is opened during the negative cycle, the diodes D_4 , D_5 and D_6 are forward biased and current keeps on streaming in two ways as shown in Fig. 2(d). The signal across the load becomes unidirectional during both positive and negative cycles of the input supply, thus AC-DC transformation is accomplished.

B. Ideal Voltage Equation

From the proposed circuit as shown in Fig. 1(a), at the input stage:

When the switch is ON,

$$V_{L_1} = V_{in} \quad (1)$$

When the switch is OFF,

$$V_{L_1} = V_{in} - V_{c_1} - V_o \quad (2)$$

At the output stage:

When the switch is ON,

$$V_{L_3} = -V_{c_1} \quad (3)$$

When the switch is OFF,

$$V_{L_3} = V_o \quad (4)$$

The final expression of output voltage can be written as,

$$V_{O_{AV}} = \frac{2DV_{inmax}}{\pi(1-D)} \quad (5)$$

C. Feedback Control to Improve Power Factor

Power quality of power system is governed by its power factor. Open loop activity of conventional AC-DC converters experience low power factor which causes few problems in the overall electrical network. To solve this issue, the proper design of the feedback controller is of crucial significance to enhance the overall performance of the system.

The designed controller of Fig. 3 creates two control loops to provide the necessary PWM signal to drive the switch of the proposed SEPIC converter: inner current loop and outer voltage loop.

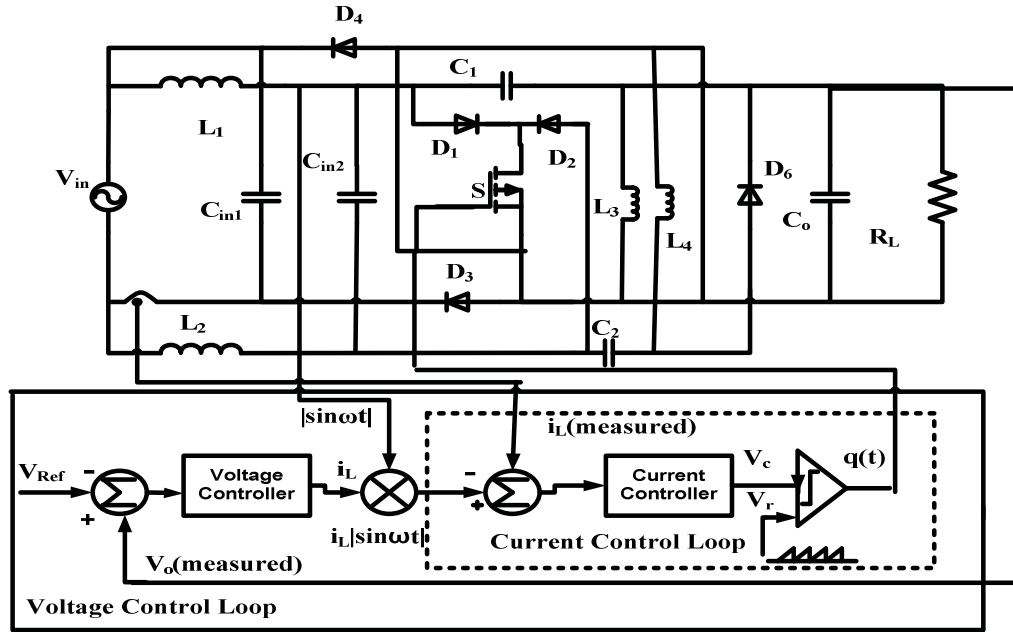


Fig. 3 Proposed converter with feedback control to improve power factor and reduce THD

IV. SIMULATION RESULTS

TABLE I. SPECIFICATION OF DESIGN PARAMETERS FOR OPEN LOOP CONTROL

Parameter	Value
Input Voltage (V_i)	220V
Switching Frequency (F_s)	8kHz
Inductor (L_1, L_2)	2.8mH
Inductor (L_3, L_4)	1.8mH
Capacitor (C_1, C_2)	0.8 μ F
Input Capacitor (C_{in1}, C_{in2})	5.5 μ F
Output Capacitor (C_0)	220 μ F
Load Resistor (R_L)	100 Ω

TABLE II. PERFORMANCE ANALYSIS OF PROPOSED CIRCUIT FOR DIFFERENT DUTY CYCLES

Duty Cycle	Proposed Circuit				Conventional Circuit			
	η (%)	THD (%)	PF	Voltage gain	η (%)	THD (%)	PF	Voltage gain
0.1	89	31	.35	0.3	75	100	.5	.2
0.2	95	48	.71	0.6	90	98	.65	.4
0.3	96	39	.88	1.01	94	81	.77	.7
0.4	97	28	.94	1.41	95	56	.86	.9
0.5	97	20	.97	1.81	96	41	.9	1.41
0.6	98	16	.98	2.28	95	43	.9	2
0.7	97	31	.94	3.3	94	38	.9	2.9
0.8	97	31	.86	4.9	91	30	.89	4.3
0.9	92	33	.74	6.9	80	43	.87	7.27

The simulation of the conventional and proposed SEPIC AC-DC converter was performed using PSIM 9.1 environment. Table I contains the design parameters used for simulation. In Table II, performance outcome of both conventional and proposed single phase AC-DC SEPIC converter are shown by varying duty cycle for the constant

load of 100 Ω and switching frequency of 8 KHz, whereas in Table III, for the same switching frequency, the circuit performances have been observed by varying the loads and keeping the duty cycle fixed at 50%. The performance parameters presented in Table II and III are efficiency (η), power factor (PF), total harmonic distortion (THD) and voltage gain. It is evident from the tables that the proposed circuit performs better than the traditional SEPIC converter with respect to the measured parameters.

TABLE III. COMPARISON OF PROPOSED CIRCUIT WITH CONVENTIONAL CIRCUIT UNDER LOAD VARIATION

Load (Ω)	Proposed Circuit				Conventional Circuit			
	η (%)	THD (%)	PF	Voltage gain	η (%)	THD (%)	PF	Voltage gain
50	97	27	.96	1.43	96	41	.91	1.25
70	96	20	.97	1.53	96	47	.91	1.37
90	96	20	.97	1.72	96	43	.91	1.40
110	95	21	.97	1.90	96	40	.92	1.42
130	95	21	.97	2.05	95	41	.92	1.42
150	94	21	.97	2.20	94	42	.91	1.54

Comparison for efficiency, power factor, input current THD and voltage gain of the proposed AC-DC SEPIC converter with conventional SEPIC converter with duty cycle variation is given graphically in Fig. 4 where it is clear that proposed circuit performs better than the conventional circuit. In Fig. 4(c) and 4(d) value of THD and voltage gain go up after 80% of duty cycle due to the enhancement mode of MOSFET switch. Comparison between efficiency, input current THD, power factor and voltage gain of the proposed AC-DC SEPIC converter with conventional SEPIC converter with load variation is given in Fig. 5. Variation of loads does not deteriorate the circuit's performance which makes the proposed converter more effective.

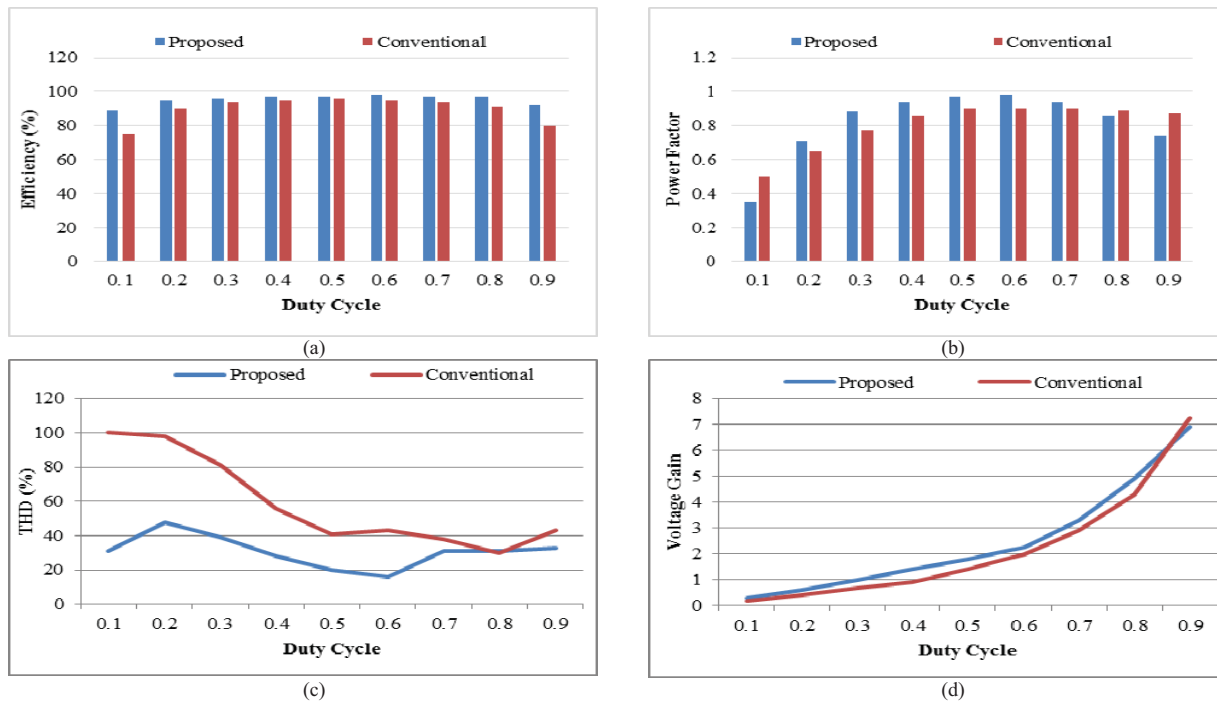


Fig. 4 Graphical representation of efficiency (a), power factor (b), input current THD (c) and voltage gain (d) for the Proposed AC-DC SEPIC converter with conventional SEPIC Converter under duty cycle variation.

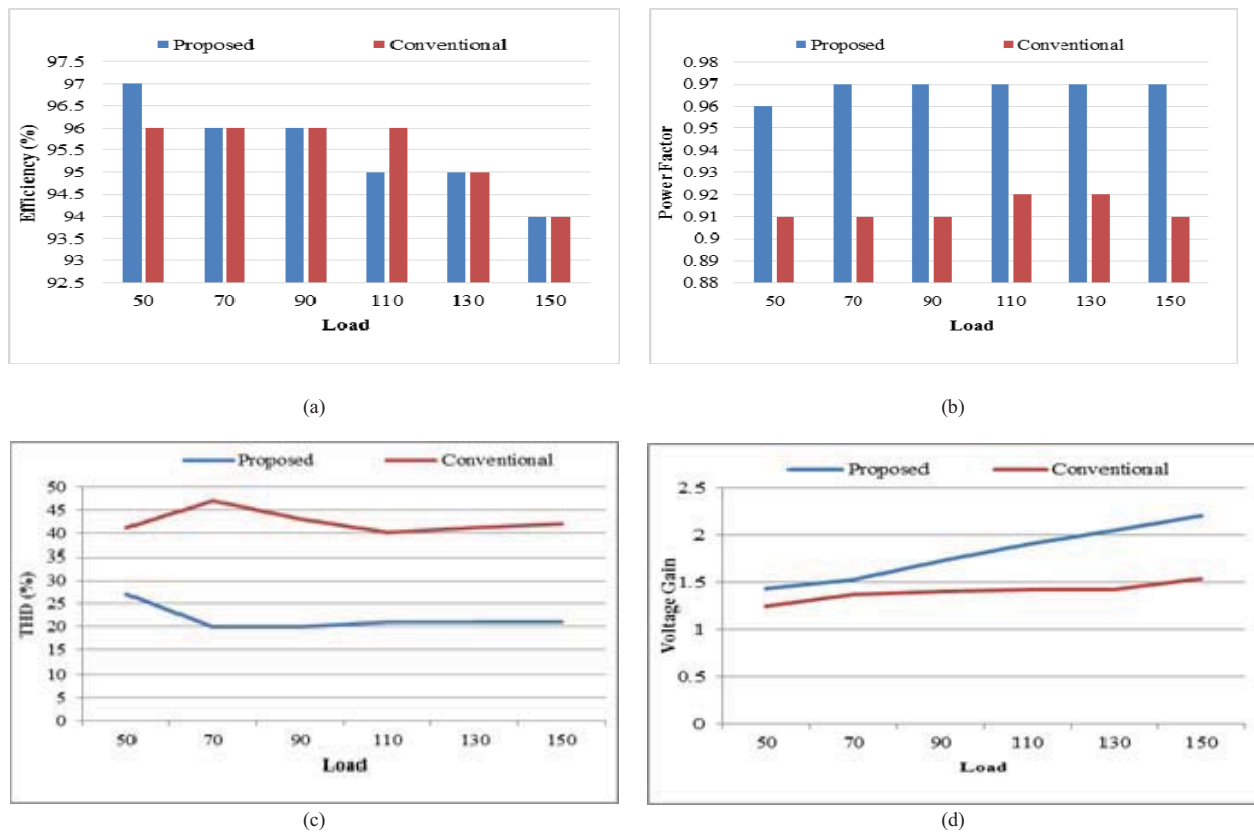


Fig. 5 Graphical representation of efficiency (a), power factor (b), input current THD (c) and voltage gain (d) for the proposed AC-DC SEPIC converter with conventional SEPIC converter under load (Ω) variation.

The input-output waveforms of the proposed input switched SEPIC converter in open loop is given in Fig. 6.

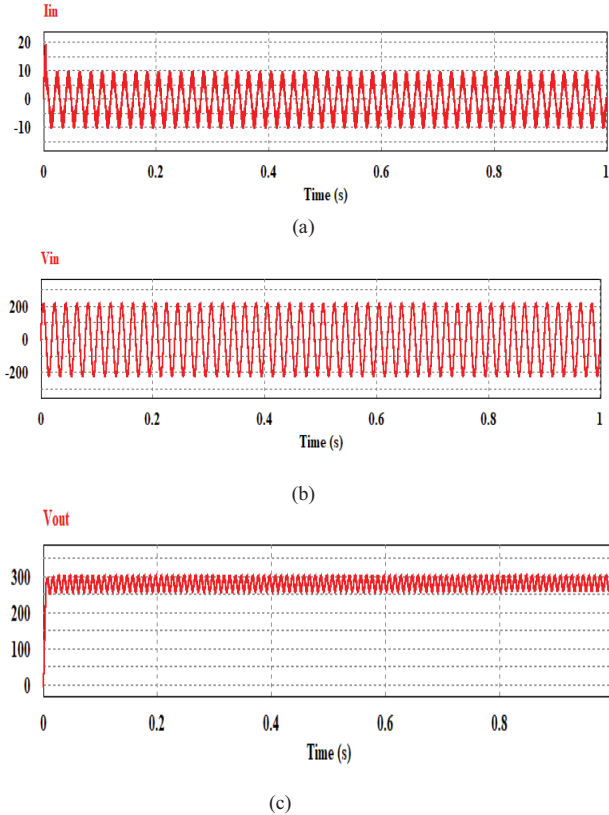


Fig. 6 Waveforms of the proposed input switched AC-DC SEPIC converter. (a) Input voltage, (b) Input current and (c) Output voltage.

In open loop operation the simulation waveform of the input current contains some harmonic due to utility voltage which may be caused by the effect of load variation on the generator. To reduce the harmonic contamination in the input current feedback controller is used.

Simulation of circuit of Fig. 3 has been done for the proposed converter with feedback controller. The parameters of the proposed circuit are given in Table IV. The PFC controller is designed to obtain an average output voltage of 282 V_{dc}. The simulation results of the designed controller as compared to conventional circuits is given in Table V. Typical input-output waveform of the proposed controller is shown in Fig. 7.

TABLE IV. PARAMETER TABLE FOR CLOSE LOOP CONTROLLER

Parameters	Value
Nominal Input AC Source Voltage (V_1)	220V
Switching Frequency (F_s)	30kHz
Inductors (L_1, L_2)	2.8mH
Inductors (L_3, L_4)	0.1mH
Capacitor (C_o)	220 μ F
Resistor (R_L)	100 Ω
Gain of Voltage Sensor (V_{SEN1}, V_{SEN2})	0.005, 0.0373
Gain of Current Sensor (I_{SEN1})	1

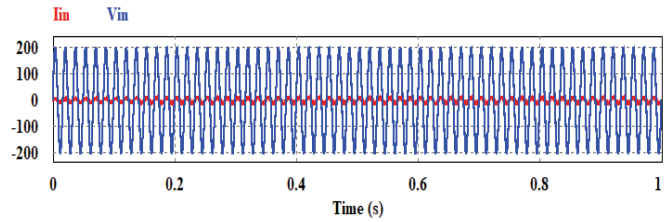


Fig. 7 PFC controlled waveforms of the input voltage and current of Fig. 3.

TABLE V. COMPARISON BETWEEN THE CONVENTIONAL AND PROPOSED AC-DC CONVERTER FOR BOTH WITHOUT FEEDBACK AND WITH FEEDBACK CONTROL

Performance Parameters	Conventional SEPIC Converter	Proposed SEPIC Converter without Feedback	Proposed SEPIC Converter with Feedback
Input Current THD	.77	.34	.15
Input Power Factor	.8	.89	.99

Table V summarizes the outcome of the proposed converter and conventional converter both with and without feedback controller. The input power factor of conventional SEPIC is .8 alongside input current distortion of 0.77. In the proposed SEPIC converter without PFC, the THD falls to 0.34 and the power factor improves to 0.9. On the other hand, the THD reduces drastically to .15 after adding feedback controller. Also, the power factor remains high at 0.99. So, the proposed converter with feedback gives 55% less THD than without feedback. So, the overall performance of the converter is improved.

V. CONCLUSION

A single phase input switched AC-DC SEPIC converter with PFC controller has been designed aiming towards higher efficiency. The aim has been achieved and verified via simulation work. Comparison has been made amongst conventional SEPIC converter, proposed SEPIC converter with and without PFC circuit. The results show optimized performance operation for the converter with feedback. The power factor is almost near unity and the total harmonic distortion is within prescribed IEEE limit. In future, the proposed SEPIC converter's performance can be further evaluated through hardware implementations alongside home appliance and industrial applications.

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