International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-3, January 2019

A New Single Switch AC/DC Converter with Extended Voltage Conversion Ratio for SMPS Applications

L. Sri Sivani, Nagi Reddy B, K. Subba Rao, A. Pandian

Abstract: ***A single switch AC/DC converter for SMPS applications is proposed in this paper for attaining extended voltage conversion range and unity input power factor. This AC/DC converter have a buck-boost PFC circuit that operates in discontinuous conduction mode (DCM) to attain unity input power factor and a buck converter to achieve tightly regulated voltage along with wide conversion range. Buck converter is also chosen to operate in discontinuous conduction mode because of its advantages like, zero switch current at turn-ON, low switching voltage stresses, independent voltage stresses from load variations and higher efficiencies. The proposed converter doesn't require extra control technique to achieve unity power factor. The detailed operation is analysed and the essential equations are derived. To analyze the effectiveness of the proposed converter, MATLAB/SIMULINK software is used.***

Index Terms: ***Wide voltage conversion range, AC/DC Converter, Unity input power factor, Buck-boost buck converter, Single-switch.***

I. INTRODUCTION

In present days AC-DC converters are much important because of their applications such as renewable applications, EV's, battery storage systems, switch mode power supplies (SMPS), LED drivers etc [1]., In general, to meet harmonic standards without the need of a bulky and costly input filter PFC based ac/dc converters are allowed and are obligatory in AC-DC converters. Therefore a PFC converter is added at the input side (first stage) followed by a DC-DC regulator. But, the two stage AC-DC converters require two controlled techniques to control the switches. This will increase the complexity, size and cost of the converter, so to eliminate these complexities single stage single switch converter [2] has been introduced. These converters can produce PFC capabilities [3], regulated output DC voltages with high efficiencies. In DC-DC converters voltage conversion ratio M (d_1) [4] is a significant factor. But, the major disadvantages of these converters are limited voltage conversion ratio M (d_1) and high switching voltage stresses. So to get wide range of voltage conversion ratio, Researches are emergent to integrated converters.

In integrated converters two conventional converters are integrated by sharing a single switch. In integrated converters there are several combinations like buck-flyback converters, buck-boost-flyback converters[4] [5]etc., In this manuscript a new single stage single switch integrated converter is projected, formed by cascading of buck-boost converter at input side because of its better PFC capabilities over other conventional converters with buck converter at output side [6] because of its step down capabilities. An inverted isolated transformer is used between buck-boost and buck converters for SMPS applications and it reduces the noise and improves power quality [7].

When PFC stage operated in continuous conduction mode it results in higher harmonic currents and less power factor correction. So to get better power factor, the buck-boost converter stage in the projected converter is always operated in discontinuous conduction mode (DCM) [8] and eliminates extra control complexity for achieving unity power factor. Buck converter is operated either in continuous conduction mode (CCM) or discontinuous conduction mode (DCM). When it operates in DCM there are many advantages like unity input power factor, switch zero current turn-ON [9], high efficiencies, less voltage stresses on switch and capacitor [10] and are independent to load.

The advantages of projected converter are-

(a) Non-inverted output is obtained.
(b) With the number of secondary windings of transformer, multiple outputs can be achieved.
(c) Very less %THD with unity input power-factor.
(d) Higher efficiencies are achieved because of zero turn-ON losses.
(e) Wide range of voltage conversion ratio.

II. PROPOSED SINGLE SWITCH AC/DC CONVERTER

A. Converter Topology

Fig.1 shows the circuit diagram of projected single stage single switch isolated buck-boost buck converter topology connected to the diode bridge rectifier (DBR).

The Inductors L_1, L_2 in the projected converter are operated in discontinuous conduction mode (DCM). Both the inductors are energized when switch S_1 is activated.

Manuscript published on 30 January 2019.
*Correspondence Author(s)
L. Sri Sivani, M.Tech, Dept. of Electrical and Electronics Engineering, KLEF, Vaddeswaram, Guntur, India.
Nagi Reddy B, Ph.D, Dept. of Electrical and Electronics Engineering, KLEF, Vaddeswaram, Guntur, India.
K. Subba Rao, Principal, Dept. of Electrical and Electronics Engineering, KLEF, Vaddeswaram, Guntur, India.
A. Pandian, Professor, Dept. of Electrical and Electronics Engineering, KLEF, Vaddeswaram, Guntur, India.

B. Operating Modes

To understand the current direction among the diodes, there are four modes which are explained briefly. The current of the components at different modes when switch S_1 is ON are shown in Fig.2.

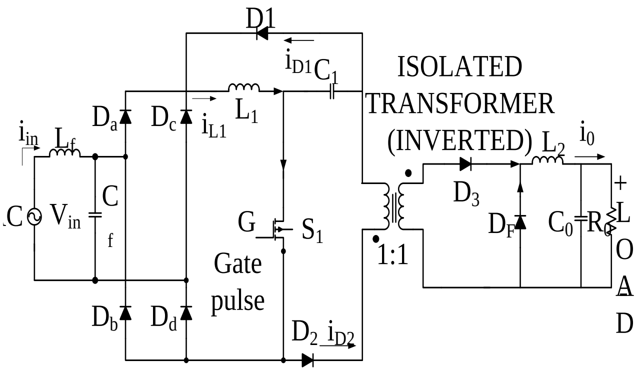


Fig. 1: Isolated buck-boost buck converter

(a)Mode-1: Gate signal of the switch S_1 is set to high i.e., turn ON. Fig. 3(a) shows the circuit diagram of mode-1 and its current path. Diodes D_2 and D_3 are in forward bias and inductors L_1 and L_2 starts charging and diodes D_1 and D_F are in reverse bias and current in capacitor C_1 is negative.

(b)Mode-2: Gate signal of the switch is set to low to turn off switch S_1. Inductors currents L_1 and L_2 gets discharge through diodes D_1 and D_F respectively as they are forward biased. Fig. 3(b) shows the path of inductor currents during this mode. The current in capacitor C_1 is positive as it charges through inductor L_1. In this interval, diodes D_2 and D_3 are reverse biased.

(c)Mode-3: Gate signal of the switch S_1 is still in turn off state. Fig. 3(c) shows the current path and its circuit diagram. The inductor L_2 is continued to discharge through the free-wheeling diode D_F and the capacitor C_1 current becomes zero at this instant.

(d)Mode-4: This mode will exists for a while before the switch is turn ON (mode-1). The inductor L_2 is completely discharged so the diode D_F will become reverse biased. The output filter capacitor C_2 feeds the load which is shown in figure 3(d). The time period of this mode depends on selection on inductor L_2 (DCM/BCM).

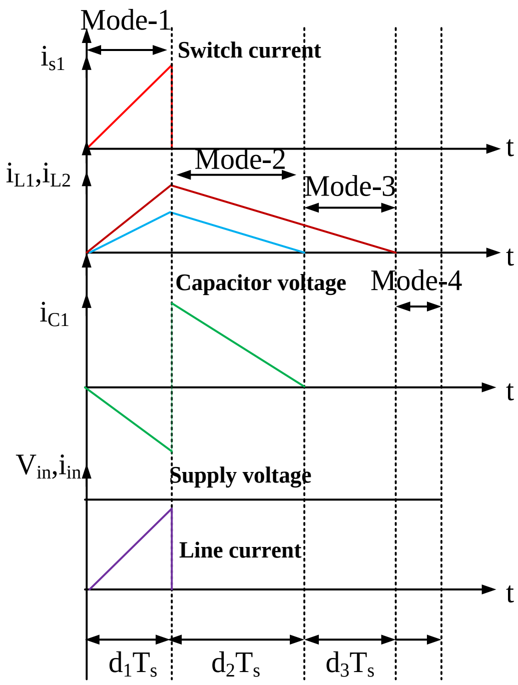
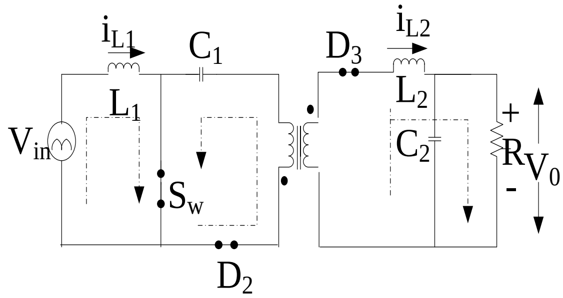
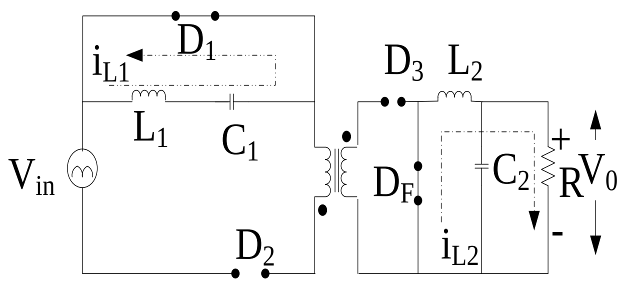


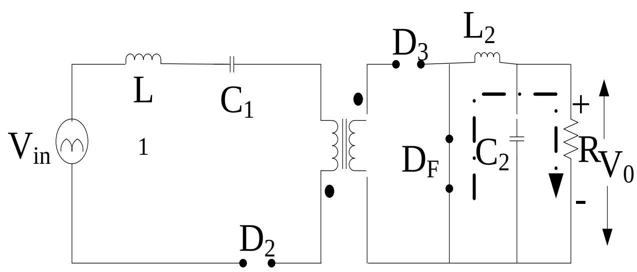
Fig. 2: Model waveforms of buck-boost buck converter



(a) Mode-1

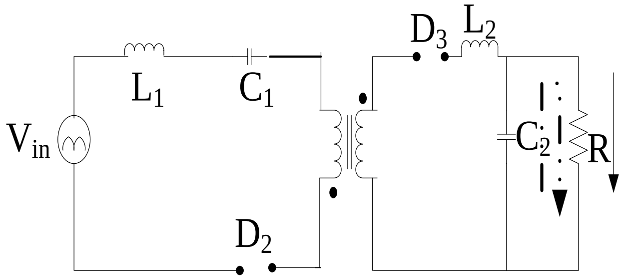


(b) Mode-2



(c) Mode-3

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)



(d) Mode-4

Fig.3: Operating modes of isolated converter

III. DESIGN ANALYSIS

Considering sinusoidal supply voltage v_{in}=V_{in}sin(ωt). The input voltage V_{in} magnitude is fairly constant because of f_s >> f_L. So peak value of current pulse is directly proportional to V_{in}. Therefore the average input current of each pulse can be represented as-

$$(i_{in}) = \frac{i_{inp}}{2T_s} d_1 T_s = \frac{d_1^2 V_{in}}{2L_1 f_s} |\sin \omega_L t| \tag{1}$$

Where i_{in} is input current, i_{inp} is peak value of each current pulse. From equation (1) it can be sensible that input line current is in sinusoidal shape and in phase with supply voltage v_{in}. Thereby input power P_{in} can be written as,

$$(P_{in}) = \frac{1}{2} V_{in}(i_{inp}) = \frac{d_1^2 V_{in}^2}{4L_1 f_s} \tag{2}$$

As the converter operated in DCM, the turn's ratio can be derived as [11]

$$V_{C1} d_1 N_1 = V_0 d_2 N_2 \tag{3}$$

where V_{C1} is voltage across capacitor,d_1 is duty ratio of buck-boost stage, N_1 is no. of turns at primary side of transformer, V_0 is voltage across load, d_2 is duty ratio of buck stage and N_2-no.of turns at secondary side of transformer.

A. Expression for output voltage

As the load is resistive, the output power can be determined as

$$P_0 = V_0 I_0 \tag{4}$$

$$P_0 = \frac{V_0^2}{R} \tag{5}$$

Assuming lossless converter, by equating equations (2) & (5), the output voltage expression is derived as

$$\frac{d_1^2 V_{in}^2}{4L_1 f_s} = \frac{V_0^2}{R} \tag{6}$$

$$\frac{d_1^2 V_{in}^2 R}{4L_1 f_s} = V_0^2 \tag{7}$$

$$V_0 = \frac{d_1 V_{in}}{2} \sqrt{\frac{R}{L_1 f_s}} \tag{8}$$

B. Expression for voltage conversion ratio M (d₁)

From equation (8), the voltage conversion ratio $M(d_1)$ can be written as

$$M(d_1) = \frac{V_0}{V_{in}} = \frac{d_1}{2} \sqrt{\frac{R}{L_1 f_s}} \tag{9}$$

For simplification, equation (9) can be written in the terms of 'k' as

$$M(d_1) = \frac{V_0}{V_{in}} = \frac{d_1}{\sqrt{2k}} \tag{10}$$

Where 'k' is the critical factor, given by

$$k = \frac{2L_1 f_s}{R} \tag{11}$$

To operate the converter in DCM, by applying volt-sec principle at the input inductor from figure (2) and it can be written as

$$\frac{V_{in}}{L_1} d_1 T_s - \frac{V_{C1}}{L_1} d_2 T_s = 0$$

$$d_1 = d_2 \frac{V_{C1}}{V_{in}} \tag{12}$$

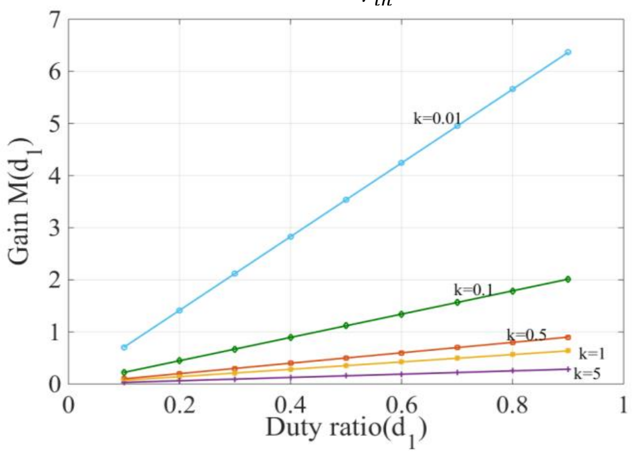


Fig. 4: Voltage conversion ratio M (d₁) versus duty ratio 'd₁' for different 'k' values

The design analyses of reactive components in the converter L_1, L_2, C_1, C_0 are discussed in this section. To minimize the output voltage ripple, output filter capacitor C_0 is selected as large. So that output voltage V_0 will be constant and output filter will not affect the circuit operation. The inductor values L_1 &L_2 are selected to operate in DCM. The ripple of i_{L2} is selected such that it is closely operated to BCM. The input inductance L_1 for lossless converter can be written from equation (2) as

$$L_1 = \frac{d_1^2 V_{in}^2 T_s}{4P_{in}} = \frac{d_1^2 V_{in}^2 T_s}{4P_0} \tag{13}$$

To calculate storage capacitor C_1, for low-frequency peak-to-peak capacitor voltage ripple (ΔV_{C1}) can be obtained as

$$\Delta V_{C1} = \frac{d_1^2 V_{in}^2 T_s}{8\pi L_1 f_L V_{C1}} \frac{1}{C_1} \tag{14}$$

The voltage ripple (ΔV_{C1}) of storage capacitance C_1 is given by

$$C_1 = \frac{d_1^2 V_{in}^2 T_s}{8\pi L_1 f_L V_{C1} \Delta V_{C1}} \tag{15}$$

Similarly the output inductance L_2 is

$$L_2 = \frac{(V_{C1} - V_0) d_1 T_s}{\Delta i_{L2}} \tag{16}$$

The designed parameters of the projected converter using above calculations are tabulated in table-I

Table-I: Circuit Parameters

COMPONENT	VALUES
Input voltage(V_{in})	60V(rms)
Line frequency(f_L)	50Hz

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Switching frequency(f_s)	50KHz
L_1	49Mh
L_2	32µH
C_1	350µF
C_0	3000µF
L_f	3mH
C_f	0.4µF
Resistive load(R)	5.56Ω
Duty ratio	0.3

IV. RESULTS AND DISCUSSION

The proposed model shown in Fig.1 is simulated using MATLAB /SIMULINK software. Input voltage V_{in} of the converter is tacit to be ideal. Both the inductors L_1 and L_2 are operated in DCM. i_{L2} ripple is selected such that the inductor L_2 is operated closely towards BCM. This condition reduces the ripple as well as size of inductor.

Fig. 5(a) shows that both line voltage and input current are in phase and input current of the converter is pure sinusoidal so that the harmonic content of input current is nearly unity and thus results in less losses and thereby efficiency of the converter increases. Fig. 5(b) shows the harmonic content of input current and the %THD value of input current reaches the IEC standards. The %THD value at fundamental frequency is 1.30% and it is well under the limits of IEC 61000-3-2 standards.

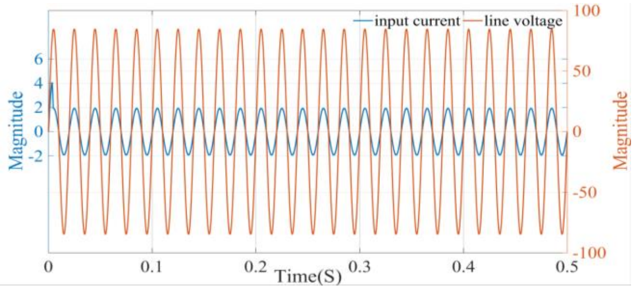


Fig. 5(a): Line voltage and input current waveform at 60V (rms)

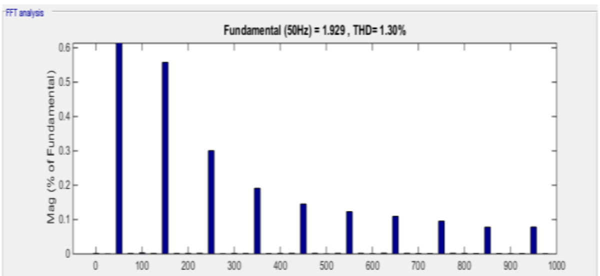


Fig. 5(b): Harmonic content of input current

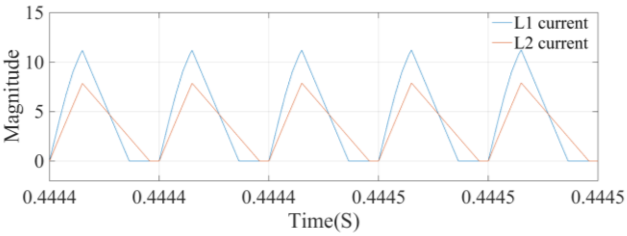


Fig.6(a): Simulation results for input inductor current (i_{L1}), output inductor current (i_{L2}).

The inductors L_1 and L_2 are operated in discontinuous conduction mode so the currents i_{L1} & i_{L2} are discontinuous and are represented in Fig. 6(a). Fig. 6(b) shows the switch voltage (V_{sw}) and switch current when the converter is operated at duty ratio of 0.3(d=0.3). From Fig. 6(b) it can be shown that the switching voltage stresses are low, which is an advantage over single-stage single switch converters.

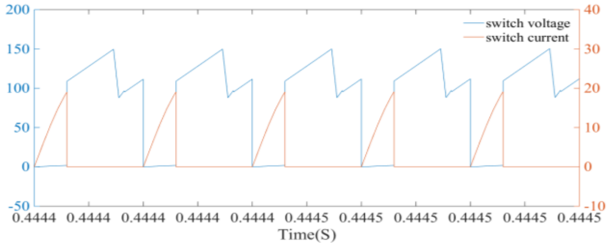


Fig. 6(b): Simulation results for switch voltage (V_s) & switch current (i_s).

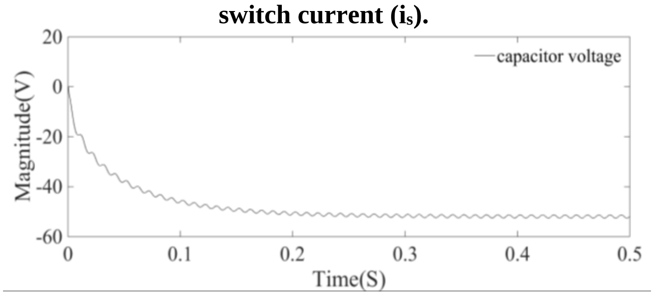


Fig. 7: Simulation results for capacitor voltage (V_{C1}).

Fig. 7 represents the intermediate bus capacitor voltage V_{C1} (≈ 57.94V) with a ripple of 10V. Fig. 8 represents the diode currents i_{D1}, i_{D2}, i_{DF} of the proposed converter. The currents i_{D2} starts from zero and i_{D1} and i_{DF} turns OFF with zero current. Hence the losses across the diodes D_1, D_2 & D_F are low, helps to improve the efficiency of the converter.

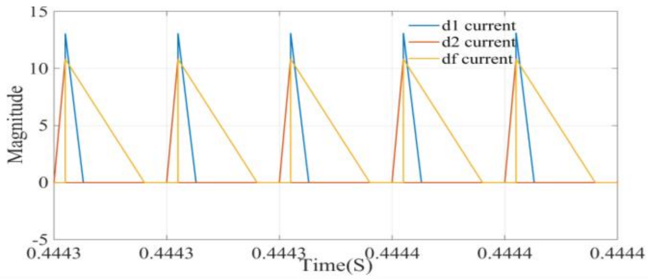


Fig.8: Simulation results for diode-1 current, diode-2 current, free-wheeling diode current.

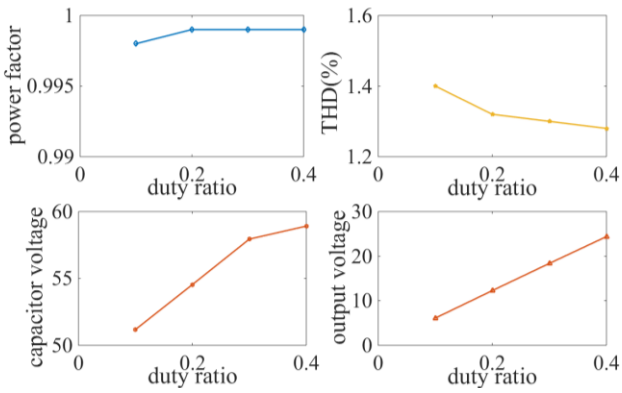


Fig.9: Plots for different duty ratio's with power factor, THD (%), capacitor voltage, output voltage.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

Table-II: Power factor, %THD, capacitor voltage, output voltage for different duty ratio's

Duty ratio	Power factor	%THD	Capacitor voltage	Output voltage
0.1	0.998	1.40	51.18	90.24
0.2	0.999	1.32	54.54	93.03
0.3	0.999	1.30	57.94	93.17
0.4	0.999	1.28	58.91	24.38

From Fig.9 shows the plots for power factor (%), THD (%), capacitor voltage and output voltage with respect to different duty ratio's for constant input voltage 60V(rms). From figure it can be seen that the power factor for different duty ratio's is nearer to unity. The %THD is also very low for the range of duty ratio's. The capacitor voltage and output voltage are proportional to duty ratio. So with the increase of duty ratio's the output and capacitor voltages will also increase as shown in Fig. 9.

Fig.10 shows the graph between duty ratio's with efficiency. From this it is observed that efficiency is ranged from 90.2% to 93.2%. Also, for very low duty ratio's (≤ 0.2 or 20%) the projected converter showed promising performance with higher efficiencies.

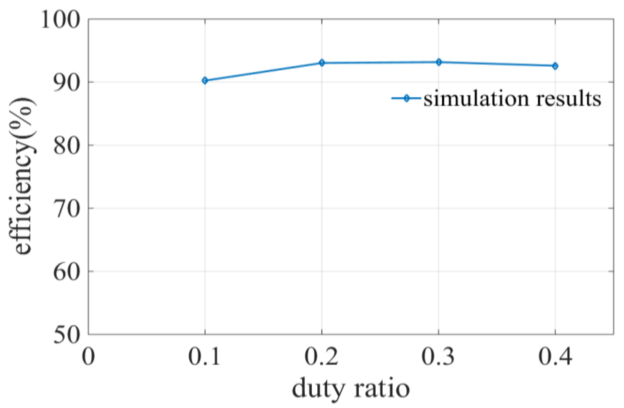


Fig.10: Simulation results with different duty ratio's for efficiency (%).

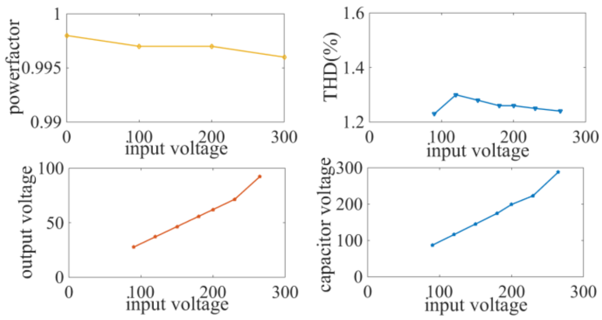


Fig.11: Plots for universal operating voltage range with power factor, THD (%), output voltage, capacitor voltage.

Table-III: Power factor, %THD, capacitor voltage, output voltage for different input voltages

Input voltage	Power factor	THD(%)	Output voltage	Capacitor voltage
90	0.99	1.23	27.73	87.08
120	0.99	1.30	37.11	116.2
150	0.99	1.28	46.55	145.5
180	0.99	1.26	55.87	174.6
200	0.99	1.26	62.12	194
230	0.99	1.25	71.5	223.2
265	0.99	1.24	92.39	288.1

Fig.11 shows the results for universal voltage ranges with power factor, THD (%), output voltage and capacitor voltage. Power factor is almost unity in all cases for duty ratio of 0.3. The THD (%) is very less and reaches the limits of IEC 61000-3-2 standards. By this it can be accomplished that the projected converter showed the better performance for the universal range of voltages.

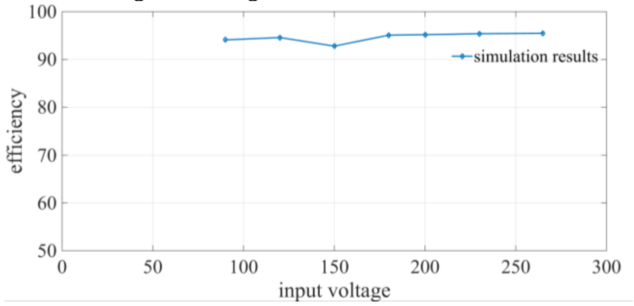


Fig.12: Simulation results for efficiency at universal operating voltage ranges.

Fig.12 shows the simulation efficiency plots with respect to universal input voltage range. From this it is observed that efficiency is ranged from 94.1% to 95.5%.

V. CONCLUSION

A new single switch AC/DC converter is proposed to attain extended voltage conversion ratio and unity input power factor. In this converter buck-boost and buck converters are integrated with an isolated transformer operated by single switch. The detailed analysis and operation of the proposed converter in discontinuous conduction mode is explained with necessary equations and operating modes. The effectiveness of projected converter is verified by using MATLAB/SIMULINK software. From equation (10), it is proved that the voltage conversion ratio is more compared to conventional converters. The proposed converter switch voltage stresses are very less (<250V) compared with other converters. Fig. 6(b) shows zero switch current at turn-ON. For all the operating conditions, the proposed converter achieved almost unity input power factor. The input current %THD is very low and satisfies IEC 61000-3-2 standards. From simulation results, it can be concluded that the proposed AC/DC converter achieved unity power factor, zero turn-ON losses, low switching voltage stresses and higher efficiencies. Hence this converter showed promising performance over the conventional single switch converters.

REFERENCES

1. "A New Family of Single Stage AC/DC Power Factor Correction Converters with Fast Output Voltage Regulation" 0. Garcia, J.A. Cobos, P. Alou, R. Prieto. J. Uceda and S. Ollero.
2. "A New Family of Single-Stage Isolated Power-Factor Correctors with Fast Regulation of the Output Voltage"Richard Red1 Laszlo Balogh Nathan 0. Sokal.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

3. “Integrated Buck-Flyback Converter as a High-Power-Factor Off-Line Power Supply” J. Marcos Alonso, Senior Member, IEEE, Marco A. Dalla Costa, Student Member, IEEE, and Carlos Ordiz.
4. “Switching converters with wide dc conversion range,” D. Maksimovic and s. cuk, IEEE Trans. Power Electron., vol. 6, no. 1, pp. 151–157, Jan. 1991.
5. “Comparison of Basic converter topologies for Power-Factor Correction,” h. Wei and i. Batarseh, in Proc. IEEE SoutheastCon 1998, pp. 348–353.
6. “Analysis, Design, Modeling, Simulation and Development of Single-Switch AC-DC Converters for Power Factor and Efficiency Improvement” Bhim Singh and Ganesh Dutt Chaturvedi.
7. “Single-stage AC-DC power-factor-corrected voltage regulator with reduced intermediate bus voltage stress”D.D.C. Lu, D.K.W. Cheng and Y.S. Lee.
8. “Improved Power Quality Switched-Mode Power Supply Using Buck–Boost Converter” Shikha Singh, Student Member, IEEE, Bhim Singh, Fellow, IEEE, G. Bhuvaneswari, Senior Member, IEEE, and Vashist Bist, Member, IEEE.
9. “Implementation of zero-current switch turn-ON based buck-boost buck type rectifier for low power applications” Nagi Reddy.B, O.Chandra Sekhar, M.Ramamoorty, International Journal of electronics (Accepted for publication).
10. “Reducing Storage Capacitance in Off-Line LED Power Supplies by Using Integrated Converters” J. M. Alonso1, D. Gacio1, A. J. Calleja1, F. Sichirollo2, M. F. da Silva3, M. A. Dalla Costa3, R. N. do Prado3.
11. “Analysis and Design of an Isolated Single-Stage Converter Achieving Power-Factor Correction and Fast Regulation” Tsai-Fu Wu, Senior Member, IEEE, and Yu-Kai Chen, Student Member, IEEE.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)