International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 9, September - 2013

AC-AC Voltage Regulation By Switch Mode PWM Voltage Controller With Improved Performance

P. K. Banerjee[1] and Kaamran Raahemifar[2]
Department of Electrical & Computer Engineering, Ryerson University, Toronto, ON, Canada

ABSTRACT

Voltage sag is an important power quality problem. It may affect domestic, industrial and commercial customers. Voltage sags may either be decreasing or increasing due to faults or change in loads. In this paper a switch mode AC to AC regulator is investigated to maintain constant voltage across the domestic appliance during the voltage deviation from the rated value. Such deviation may occur due to change in load or change in input voltage due to voltage sag of the system itself. The proposed system incorporates insulated gate bipolar transistor (IGBT) with high frequency switching technology. The Pulse Width Modulation (PWM) controls the ON/OFF time (Duty cycle) of switching devices (IGBTs) of this regulator. By regulating duty cycle of the control signal, output voltage can be maintained almost constant for wide range of input voltage variation. Simulation results show constant voltage can be achieved in either cases of increasing or decreasing input voltage as long as it is within specified limit. The Total harmonic distortion (THD) analysis for different waveforms, THD calculation and comparison for input currents have been presented in this paper.

I. INTRODUCTION

Power lines experience voltage sags due to switching lines/loads and faults somewhere in the system. Short time voltage sags may also occur because of nearby momentary periodic loads like welding and operation of building construction equipment. Voltage sags are much more common since they can be associated with faults remote from the customer. Power quality describes the quality of voltage and current [1] and is one of the important considerations in domestic, industrial and commercial applications. Power quality faced by industrial operations includes transients, sags, surges, outages, harmonics and impulses. Equipment used in modern industrial plants is becoming more sensitive to voltage sags. Both momentary and continuous voltage sags are undesirable in complex process controls and household appliances as they use precision electronic and computerized control. Major problems associated with the unregulated long-term voltage sags include equipment failure, overheating and complete shutdown. Tap changing transformers with Silicon Controlled Rectifier (SCR) switching are usually used as a solution to continuous voltage sags [2]. They require a transformer with many SCRs to control the voltage at the load which lacks the facility of adjusting to momentary changes. Some solutions have been suggested in the past to encounter voltage sag [3-4]. AC to AC voltage regulation system based on the Cuk converter have been developed by different topologies and methods [5-6].

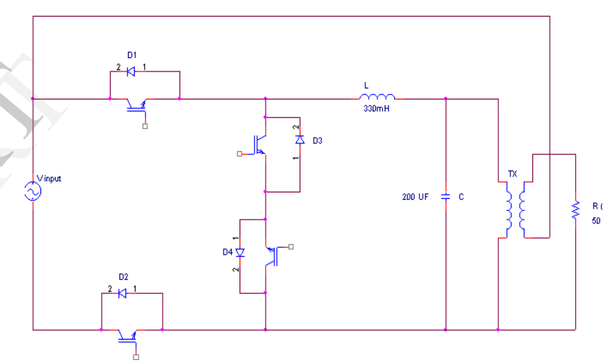


Figure 1: AC to AC Buck converter schematic

In an AC Buck converter as reported in [1], normally, a reduction of input voltage causes a decrease in output voltage. Output voltage is increased to desired value by adding a suitable voltage, which is induced in the transformer secondary as shown in Fig.1. If the input voltage is increased then output is increased. But it is necessary to decrease the output voltage to the desired value by subtracting the secondary induced voltage from input voltage. It is not possible to achieve this by buck arrangement. This limitation can be overcome by using reported AC Buck-Boost configuration [7], where output voltage is remained constant for either case of increasing or decreasing input voltage. The AC Buck-Boost configuration by using IGBT switches with manual control circuit is shown in Fig. 2.

The input-output simulation results of uncontrolled AC Buck-Boost voltage regulator for input voltage 250V, 300V and 400V (all are peak values) are shown in Fig. 3(a), (b) and (c)

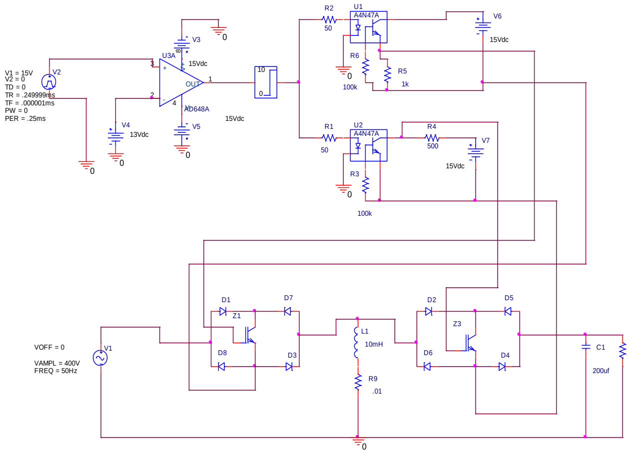
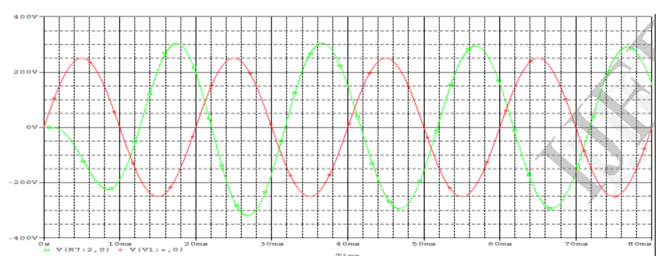


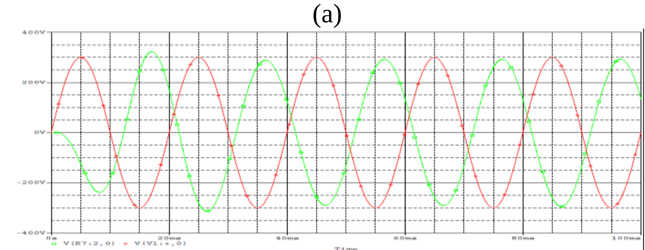
Figure 2: AC Buck-Boost converter configuration by using IGBT switches with manual control circuit

respectively. The output voltage can be remained constant when the input voltage level changes from a lower than actual input voltage level to higher than the actual input voltage level by using PWM technique.

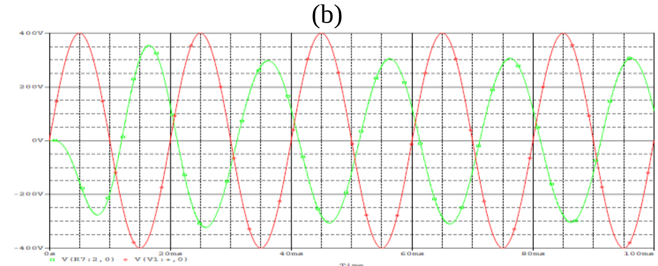
These feature have been also established by an automatic feedback control circuit for AC buck-boost voltage regulator [7] as shown in Fig. 4. It has been observed that although output always maintains constant voltage in spite of change



(a)



(b)



(c)

Figure 3: Input- Output waveforms (Buck-Boost manual controlled) when input Voltage: (a) 250V (b) 300V (c) 400V and output always maintain =300V

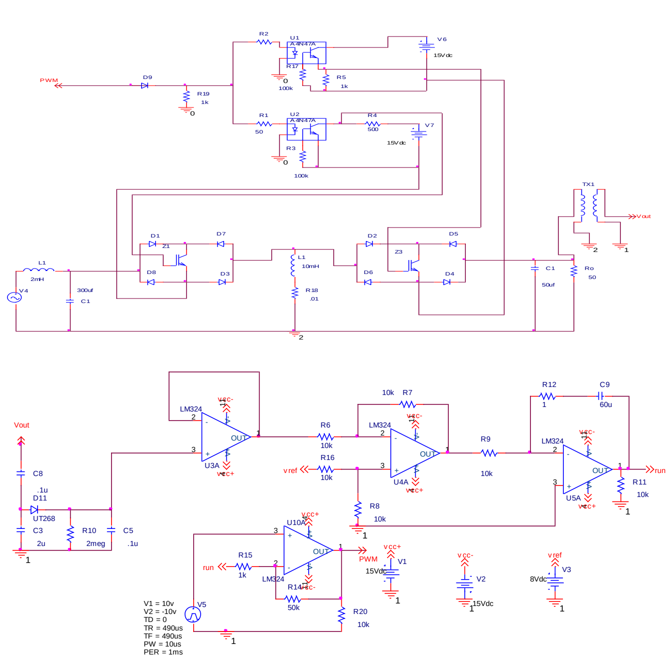
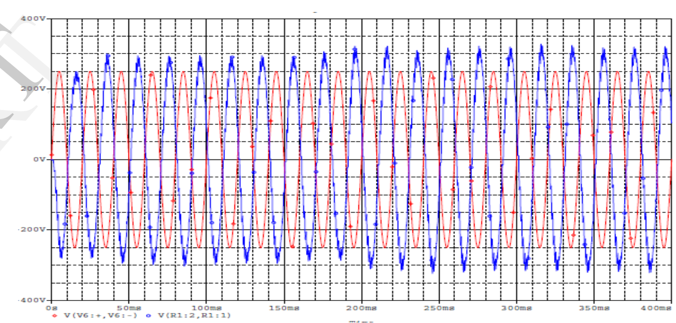
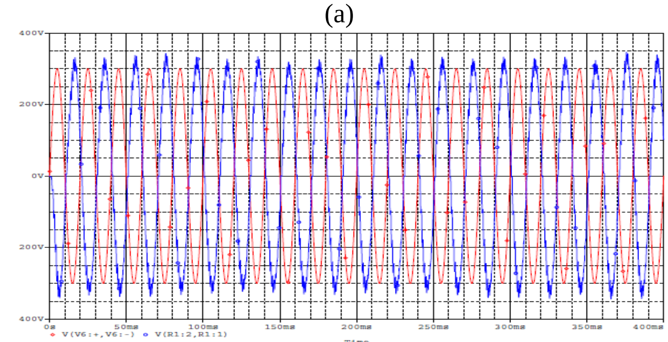


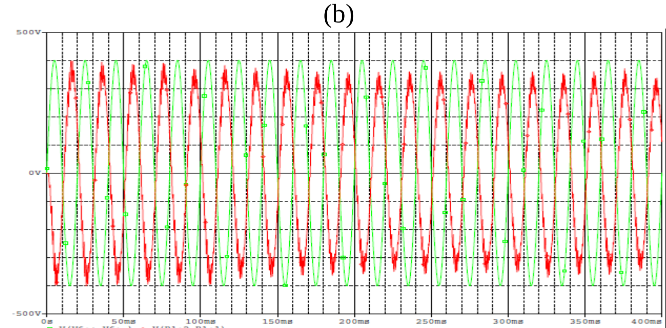
Figure 4: AC Buck-Boost converter with automatic feedback control circuit



(a)



(b)



(c)

Figure 5: Input- Output waveforms (Buck-Boost feedback controlled) when input Voltage: (a) 250V (b) 300V (c) 400V and output always maintain =300V

in input voltage, the output voltage contains significant ripple when automatic feedback control circuit is used. The simulation results for controlled AC to AC Buck-Boost regulator for input voltage 250V, 300V and 400V (all are peak values) are shown in Fig. 5(a), (b) and (c) respectively. Furthermore, it have been seen that input current is very high with more harmonics and the output current waveform which contain significant ripple also. So, it is important to further investigate removing the ripple from output voltage, output current and reduce input current and its associated harmonics. This present work is a continuation of previous research to develop a switch mode AC to AC voltage regulator to overcome above drawbacks with improved performance by using Cûk converter topology.

II. AC-AC CÛK CONVERTER TOPOLOGY

Cûk converter is similar to the Buck-Boost converter with some rearrangement. Cûk converter provides an output voltage which is less than or greater than the input voltage, but the output voltage polarity is opposite to that of the input voltage [8]. In Cûk converter, the capacitor C_1 is the medium for transferring energy from the source to the load. The implementation of AC Cûk converter by two switches is shown in Fig. 6 where output capacitor (C_2) acts as a filter. The circuit operation has been explained in positive and negative cycle as follows.

During positive half cycle of input voltage when IGBT-1(Z_1) is ON and IGBT-2 (Z_2) is OFF, the current through inductor L_1 rises and at the same time capacitor C_1 discharges its energy to the circuit formed by C_1 IGBT-1(Z1), C2, the load, L2 . When IGBT-1(Z_1) is OFF and IGBT-2(Z_2) is ON, the capacitor C_1 is charged from the input supply and the energy stored in the inductor L_2 is transferred to the load.

The operation of negative half cycle for AC input voltage

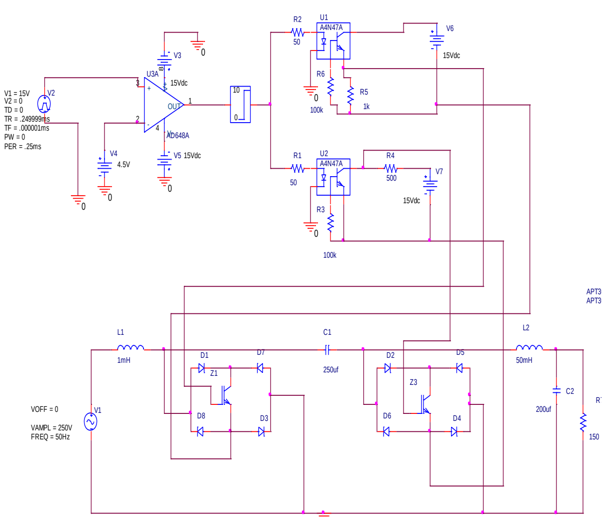
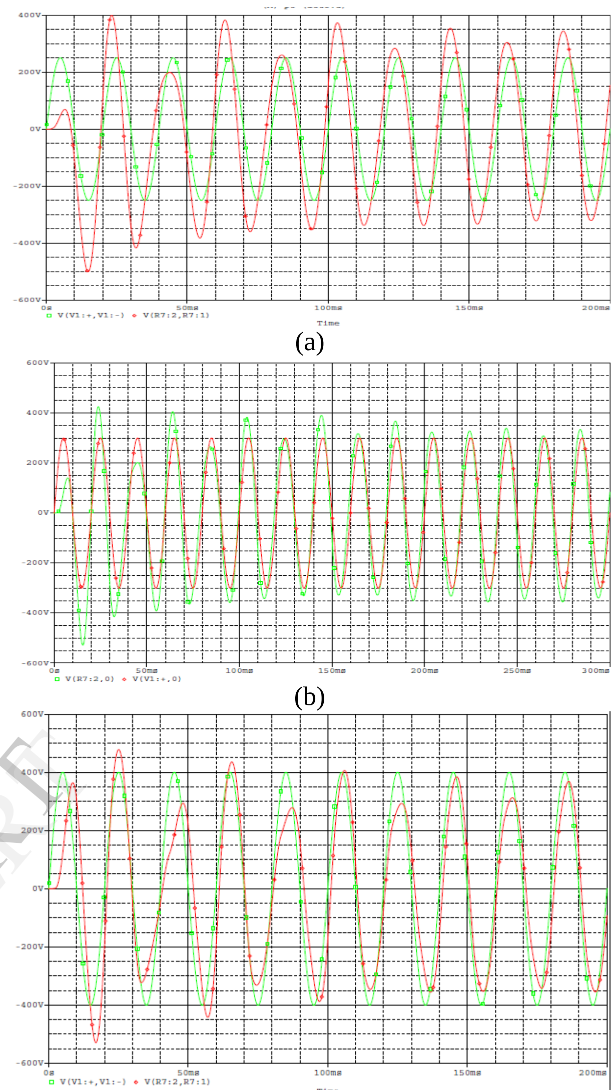


Figure 6: AC Cûk converter configuration by using IGBT switches with manual control circuit



(a) (b) (c)

Figure 7: Input- Output waveforms (AC Cûk manual controlled) when input Voltage: (a) 250V (b) 300V (c) 400V and output always maintain =300V

is the same like positive half cycle but direction is opposite. So in both cycles we get the output voltage across the load.

It is assumed that the relation between input and output voltage is the same as the DC to DC Cûk converter in ideal case. So, the voltage gain of Cûk converter [9] is given by,

$$\frac{V_0}{V_{in}} = \frac{D}{1-D}, \qquad (1)$$

and current gain is given by,

$$\frac{I_0}{I_{in}} = \frac{1-D}{D}. \qquad (2)$$

A Cûk converter can be obtained by the cascade connection of the two basic converters: the step down (Buck) converter and the step up (Boost) converter. In steady state, the output to input voltage conversion ratio is the product of the conversion ratios of the two converters in cascade. To calculate the value of filter capacitor (C_2), the following formula [10] is given by:

$$C_2 = \frac{V_o(1-D)}{8L_2 f^2 \Delta V_{c2}}. \qquad (3)$$

The input-output simulation results of above uncontrolled AC Cûk converter for input voltage 250V, 300V and 400V (all are peak values) are shown in Fig. 7(a), (b) and (c) respectively. In uncontrolled AC Cûk converter, the pulse width of switching pulses (PWM) are changed manually to maintain the constant output voltage when the input voltage level changes from a lower than actual input voltage level to higher than the actual input voltage level.

In Fig.8 shows the controlled AC Cûk converter. It is the combination of AC Cûk arrangement with automatic feedback control circuit to make proper PWM signal as per requirement. In controlled AC Cûk converter arrangement, the same feedback control circuit used as of AC Buck-Boost converter [7]. Let consider the switching frequency is 1Khz.

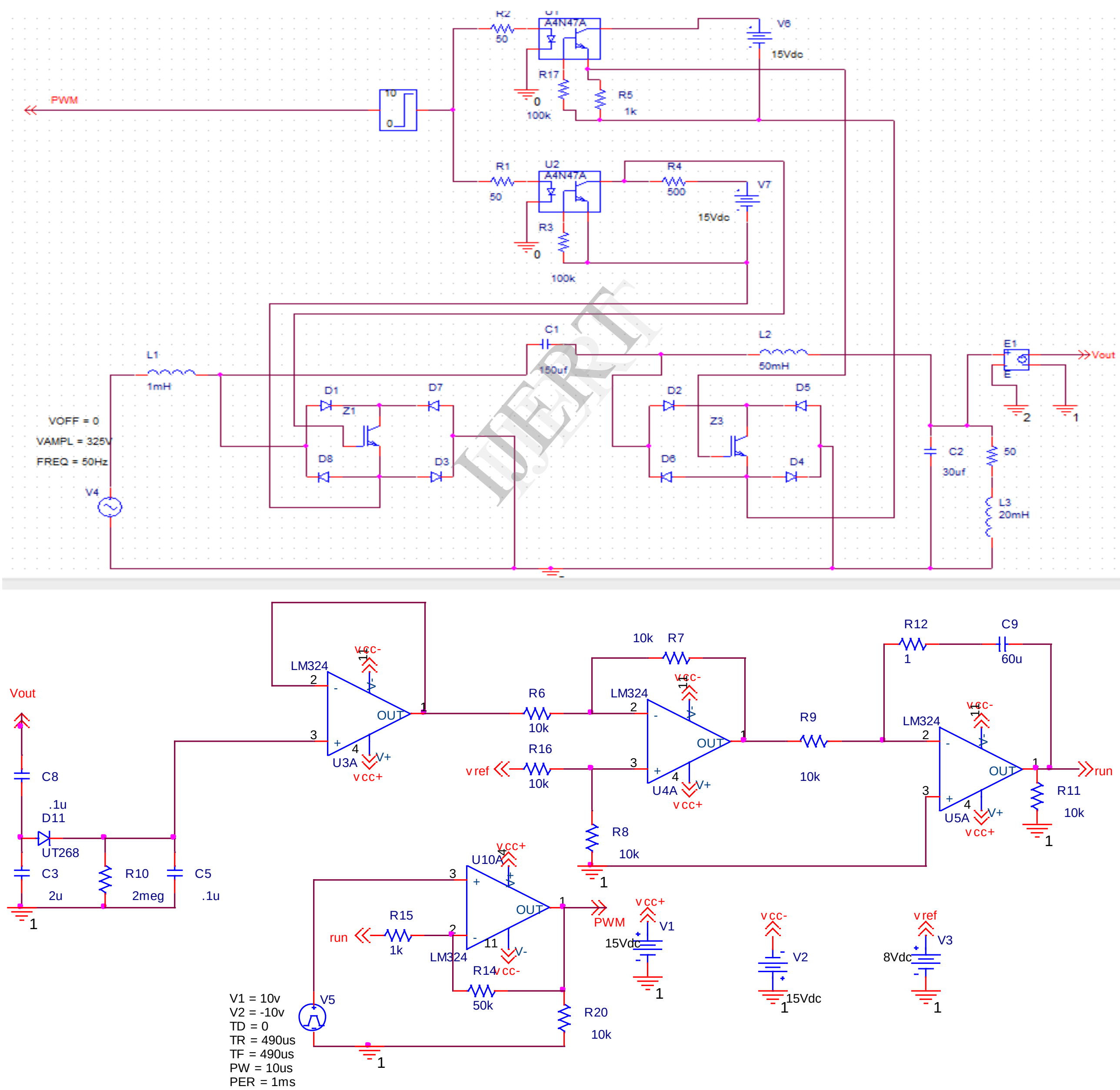


Figure 8: AC Cûk converter configuration with automatic feedback control circuit

III. RESULTS OF CONTROLLED AC-AC CÛK CONVERTER

By considering same cicuit parameter values that are already used in uncontrolled AC Cûk converter the input-output simulation results for input voltage 250V, 300V and 325V (all are peak values) have been observed. It is seen that output voltage is constant and always maintained 800V-peak value and better ripple free output than Controlled AC Buck-Boost (simulation results are not included in paper due to page limitation). To achieve the output voltage always 300V-peak value (even the input decrease or increase from its actual value) and overcome the simulation difficulties some circuit parameter values have been changed randomly. After making these arrangement of parameters value the results are shown in Fig. 9(a), (b) and (c) for the input voltage 250V, 300V and 325V respectively and output always 300V-peak value in every cases.

IV. COMPARISON OF RESULTS :BUCK-BOOST WITH CÛK CONVERTER

(A) Comparison based on input-output waveforms:

The circuits have been simulated by OrCAD (version 16.1). By comparing Fig. 3(a), (b) and (c) with Fig. 7(a), (b) and (c) respectively (for manual controlled converter-in case of AC Buck-Boost and CUK converter), it has been seen that output always maintains constant (300V-peak) by using PWM technique in both arrangements.

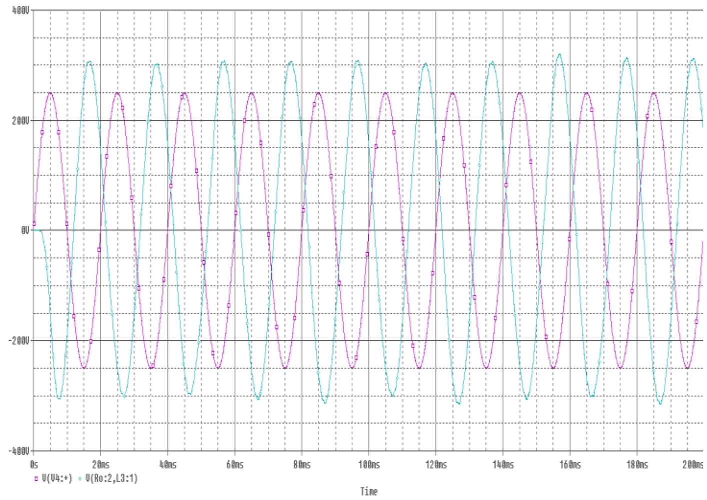
On the other hand, by comparing Fig. 5(a), (b) and (c) with Fig. 9(a), (b) and (c) respectively (for feedback controlled converter- for both cases), it has been seen that output always maintains constant (300V-peak) in both cases. It is observed that, in case of AC Cûk converter output have maintained better ripple free waveforms than AC Buck-Boost converter output.

(B) Comparison based on THD analysis:

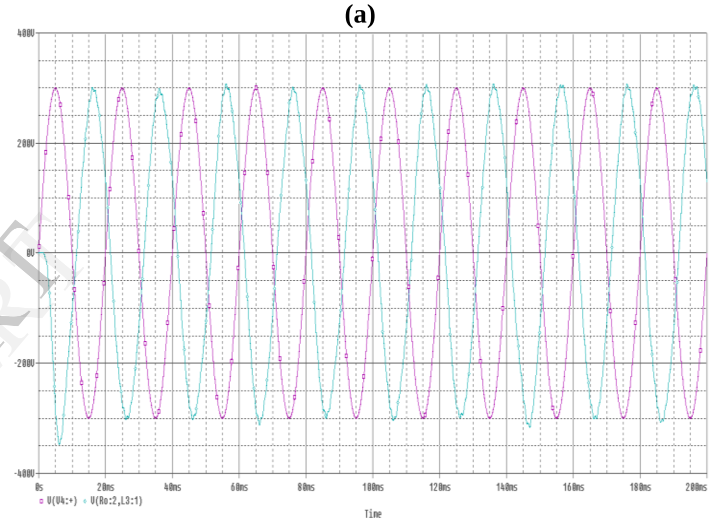
To calculate the THD values the following formula [11] is given by :

$$\text{THD}\ \% = \frac{\sqrt{\sum_{h=2}^{h=\infty} (M_h)2}}{M_1} \times 100$$

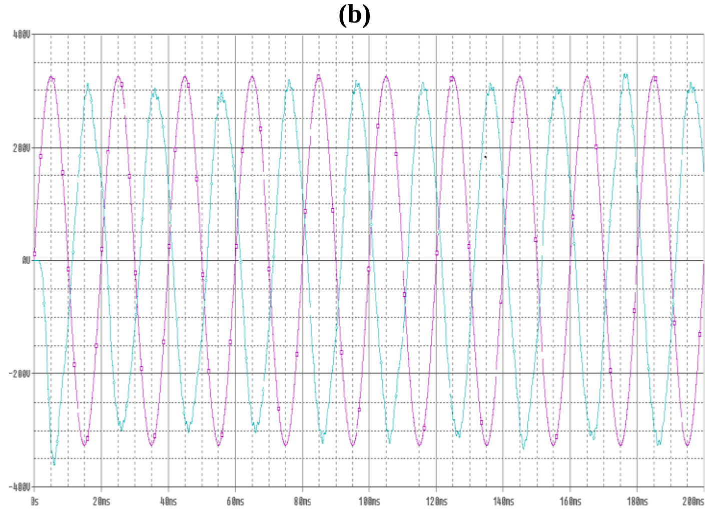
Where Mh is the magnitude of either voltage or current harmonic component and M1 is the magnitude of the fundamental component of either voltage or current. Fig.10 shows the simulated waveforms of input current, output current and output voltage of AC Buck-Boost converter (for input 325V-peak) and Fig. 11 shows the spectrums of corresponding waveform of Fig 10. Moreover, Fig.12 shows the simulated waveforms of input current, output current and output voltage of proposed AC Cûk converter (for input 325V-peak) and Fig. 13 shows the spectrums of corresponding waveform of Fig 12.



(a)



(b)



(c)

Figure 9: Input- Output waveforms (AC Cûk feedback controlled) when input Voltage: (a) 250V (b) 300V (c) 325V and respective output (300V)

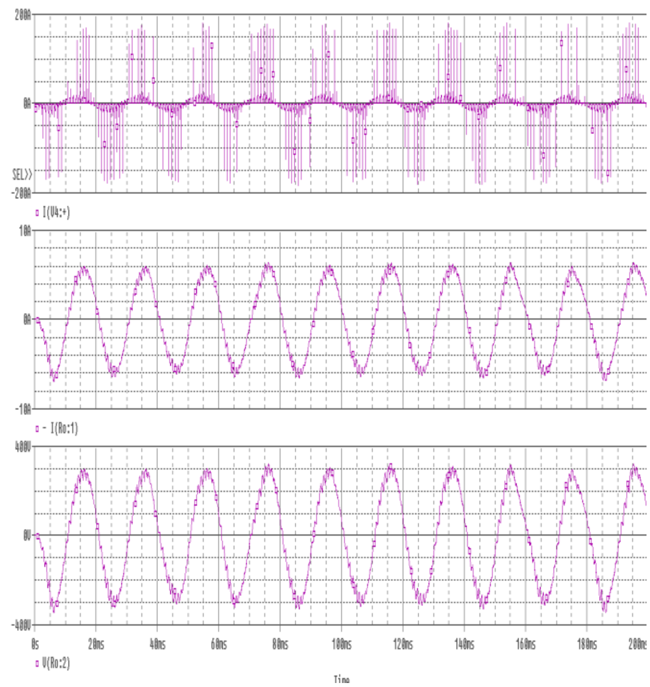


Figure 10. Input current, output current and output voltage waveform (from the top) of AC Buck-Boost Converter for input voltage 325V

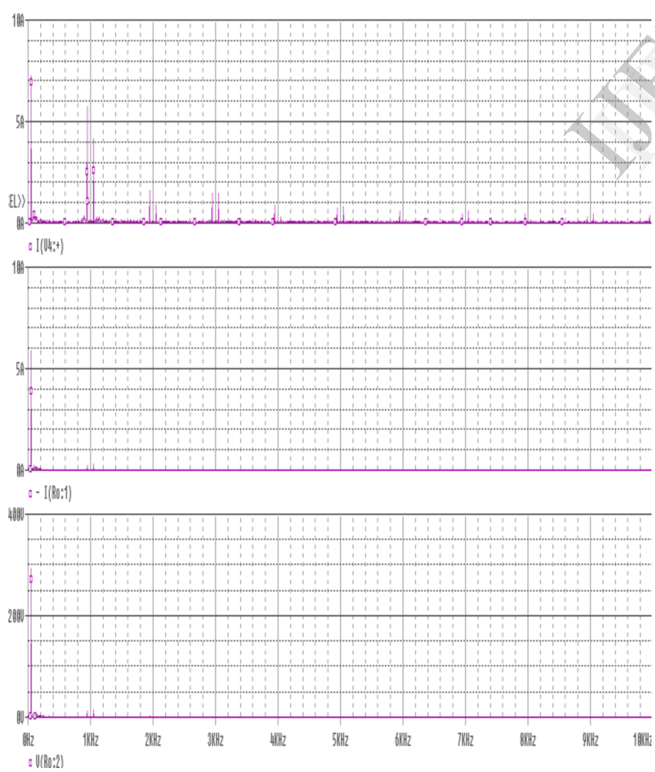


Figure 11. Spectrums of input current, output current and output voltage (from the top) of AC Buck-Boost Converter for input voltage 325V corresponding to Fig 10.

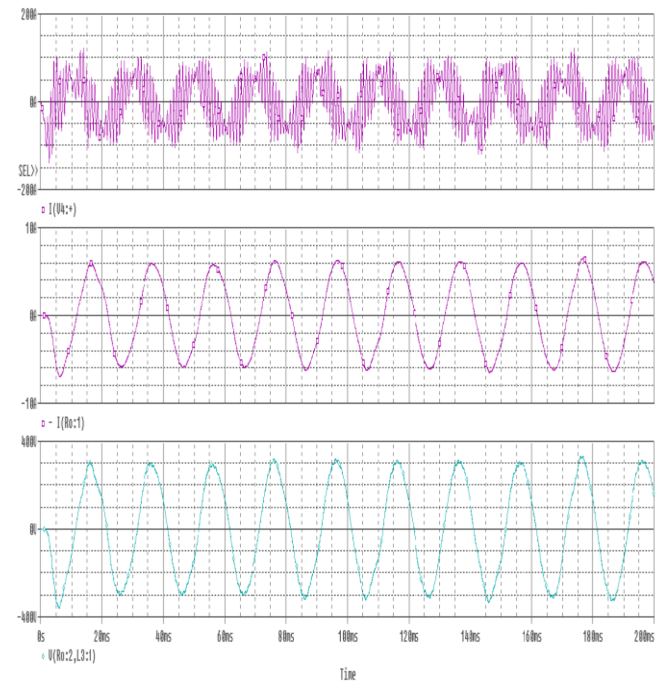


Figure 12. Input current, output current and output voltage waveform (from the top) of AC Cûk Converter for input voltage 325V

Figure 13. Spectrums of input current, output current and output voltage (from the top) of AC Cûk Converter for input voltage 325V corresponding to Fig 12.

Comparing the waveforms of Fig. 10 and 12, it have been seen that the input current contains less harmonics (spikes), the output current and output voltage waveforms contain less ripples (mostly sinusoidal) in case of AC Cûk configuration compare to the AC Buck-Boost arrangement.

Furthermore, based on spectrum analysis, according to Fig. 11 and 13, it is also observed that input current contains less harmonics (spikes), output current and output voltage waveforms contain almost no harmonics components in AC Cûk converter.

Finally, total harmonic distortion (THD) have been calculated based on spectrum analysis according to Fig. 11 and 13 by using formula in equation (4).

The calculated THD values are:

$$THD\ \% = \frac{\sqrt{(4.10)^2+(2.98)^2+(1.14)^2+(0.63)^2+(1.06)^2}}{5.12} * 100 = 104.28\%$$ (For AC Buck-Boost Converter)

$$THD\ \% = \frac{\sqrt{(21.21)^2+(22.62)^2}}{35.92} *100 = 86.32\%$$ (For AC Cûk Converter)

So, according to waveforms as well as THD values, the performance of proposed Cûk converter is better than AC Buck-Boost converter.

V. CONCLUSION

The simulation results provided in this paper shows feasibility of the AC-AC switching voltage converter for voltage sag correction by using Cûk converter topology with better performance. To get better output and performance further investigation and more research and development are needed for this arrangement. Some future works are recommended: designing output and input filter properly to minimize ripple and harmonics, formula (procedure) considering the right choice of passive elements (instead of random choice), developing feedback control circuit properly as per output requirements, proper selection of switching frequency, considering variety of loads (resistive, inductive, capacitive or any combination), performance analysis and comparison of efficiency as per duty cycle, development needed for total harmonics distortion (THD) to meet the standards like IEEE-519 and IEC 1000-3.

[

REFERENCES

[1] Steven M. Hietpas and Mark Naden, "Automatic Voltage Regulator Using an AC Voltage- Voltage Converter," *IEEE Transactions on Industry Applications*, Vol. 36, No. 1, pp.33-38, January/ February 2000.

[2] N. Kutkut, R. Schneider, T. Grant, and D.Divan, "AC Voltage Regulation Technologies," *Power Quality Assurance*, pp. 92-97, July/Aug. 1997.

[3] D. Divan, P. Sutherland, and T. Grant, "Dynamic Sag Corrector: A New Concept in Power Conditioning," *Power Quality Assurance*, pp.42-48, Sept./Oct. 1998.

[4] G. Venkataramanan, B.K. Johnson, and A. Sundaram, "An AC-AC Power Converter for Custom Power Applications," *IEEE Trans. Power Delivery*, Vol. 11, pp.1666-1671, July 1996.

[5] J.Hoyo, H.Calleja, and J.Alcala, "High-quality output PWM AC voltage regulator based on Cuk converter," *International Journal of Electronics*,Vol.92, No.4, pp. 231-242, April 2005.

[6] Z.Ling, and L.Lei, "Isolated Cuk Three-Level AC-AC Converter", *The 5th IEEE Conference on Industrial Electronics and Applications*, ICIEA, 2010, pp.1012-1017.

[7] P. K. Banerjee, M. A. Choudhury and Golam Toaha Rasul, "AC Voltage Regulation by Switch Mode BUCK-Boost Voltage Controller," *Journal of Electrical Engineering*, IEB, Vol. EE 31, No. I and II. December 2004, pp.27-31

[8] M. H. Rashid,"*Power Electronics – Circuits, Devices, and Applications*," Prenctice Hall Englewood Cliffs, Second Edition, 1993, pp.317-387.

[9] Slobodan Cûk,*"Basics of Switched Mode Power Conversion Topologies, Magnetics, and Control,"* Modern Power Electronics: Evaluation, Technology, and applications, Edited by B.K. Bose, IEEE Press, 1992, pp.265-296.

[10] Slobodan M. Cûk , "*Modelling, Analysis and Design of Switching Converter*," Ph.D Thesis, California Institute of Technology, Pasadena, California, 1977 (November 29, 1976) .

[11] Bo-Tao Lin and Yim-Shu Lee, "Power factor correction using Cúk converters in discontinuous capacitor voltage mode operation," *IEEE Trans. Industrial Electron.*, vol. 44, no. 5, pp. 648-653, Oct. 1997.