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AC Voltage Regulation by Switch Mode Buck-Boost Voltage Controller

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ABSTRACT

Voltage sag is a serious power quality problem affecting domestic, industrial and commercial customers. Voltage sags may either decrease or increase in the magnitude of system voltage due to faults or change in loads. In this paper a switch mode AC Buck- Boost regulator is proposed to maintain voltage across a medium size domestic appliance constant during long period of 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.

1. INTRODUCTION

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 as the complexity of the equipment increases. 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 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 recent past to encounter voltage sag [3]-[6].

In a 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 voltage E_b from input voltage. It is not possible to achieve this by buck arrangement. This limitation can be overcome by using proposed AC Buck-Boost configuration, where output voltage will remain constant for either case of increase or decrease of input voltage. Constant voltage can also be achieved for load variation within specified limit.

2. AC BUCK-BOOST VOLTAGE CONTROLLER

A Buck Boost controller provides an output voltage which may be less than or greater than the input voltage. The output voltage polarity is opposite to that of the input voltage. A Buck Boost 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.

Practically AC Buck Boost regulator may be implemented by three different topologies by two, three or four switches. Among the three topologies two switch implementation requires minimum switching devices. So in this paper two switch configuration is investigated. Fig.2(a) shows the AC Buck-Boost regulator implemented by two switches with gate signals for IGBT-1 and IGBT-2.

During positive half cycle of input voltage when IGBT-1(T_1) is ON, then current passes through diode D_1, IGBT-1(T_1), Diode D_2 and inductor L. The energy is stored in the inductor L. When IGBT-1(T_1) is OFF and IGBT-2(T_2) is ON the stored energy in the inductor is transferred to the output load by D_5, IGBT-2(T_2) and D_6. The operation for positive half cycle is shown in Fig.2(b).

During the negative half cycle of input current passes through inductor L, D_3, IGBT-1(T_1) and D_4, when IGBT-1(T_1) is ON and IGBT-2(T_2) is OFF. The energy is stored in the inductor L. When IGBT-1(T_1) is OFF and IGBT-2(T_2) is ON, the stored energy in the inductor is transferred to the output load by D_7, IGBT-2(T_2) and D_8. The operation for negative half cycle is shown in Fig.2(c). So in both cycles we get the output voltage across the load. Optocouplers are used for isolation. Fig.3 is the AC Buck-Boost regulator circuit. In Fig.3 the input circuit has a LC filter circuit to smooth the input current wave shape to sinusoidal current. Fig.4 is the control signal generating circuit. Combination of both circuits provides automatic AC Buck-Boost controller.

2.1 Control And Gate Signal Generation For AC Buck-Boost Controller

Figure 4 shows the automatic control and gate signal generating circuit for AC Buck-Boost Controller. V_{out} voltage (input of control circuit) is the output AC which is converted to DC by a diode. Output of the diode circuit is passed through an OPAMP buffer (U3A :+). Buffer (U3A) is used to remove the loading effect. Output of the buffer is the input to the control circuit (U4A :-). The voltage proportional to the output voltage is compared with a reference voltage in the control circuits of Figs.4(a) & 4(b) which generates a PWM pattern to switch the bidirectional switches to maintain the output voltage of the controller constant according to the reference set by the reference voltage. Controller circuit in Fig.4(a) is a circuit composed of operational amplifiers, where as the circuit in Fig.4(b) is a control circuit simulated by using commercially available SMPS circuits.

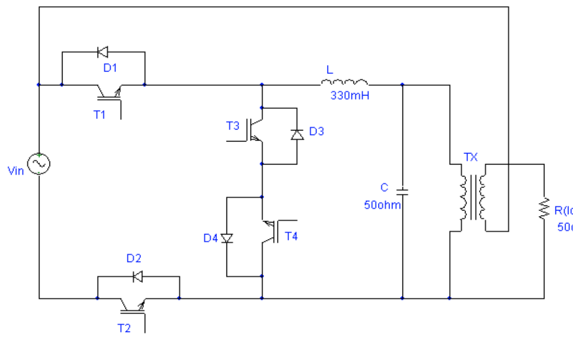


Fig. 1: AC to AC Buck converter.

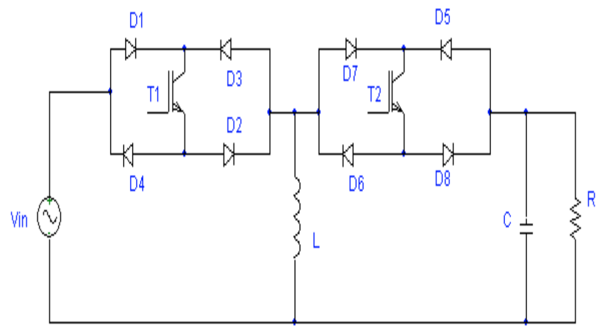


Fig. 2(a): AC Buck- Boost regulator implementation by two switches.

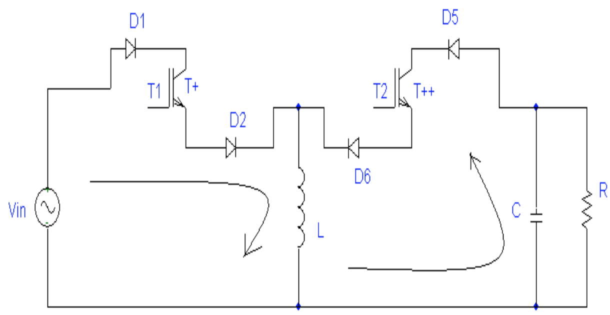


Fig. 2(b): Operation for positive half cycle.

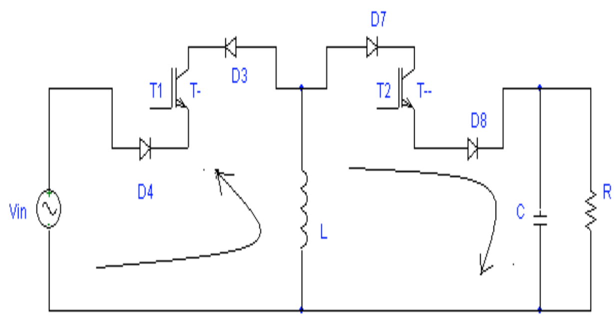


Fig. 2(c): Operation for negative half cycles.

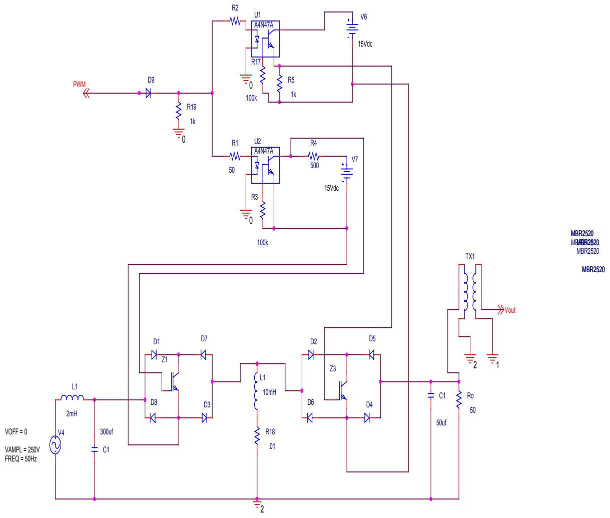


Fig. 3: AC Buck-Boost regulator circuit.

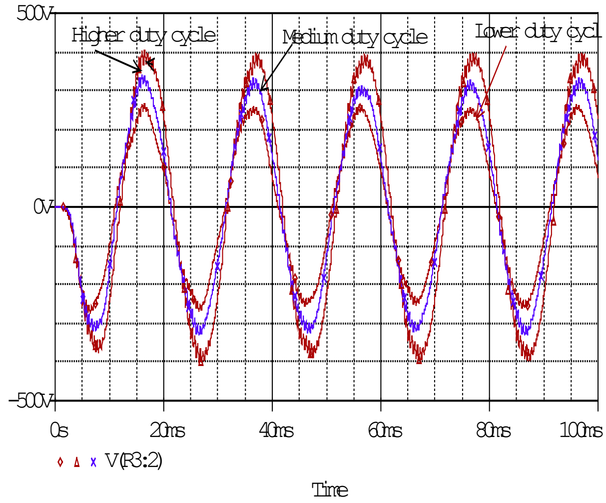


Fig. 5: Output voltage variation of AC switch mode voltage controller for variation of pulsewidth with input voltage of 300V.

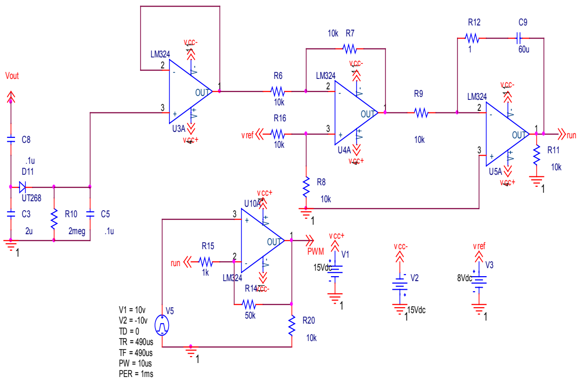


Fig. 4(a): AC Buck-Boost regulator control circuit by using operational amplifiers.

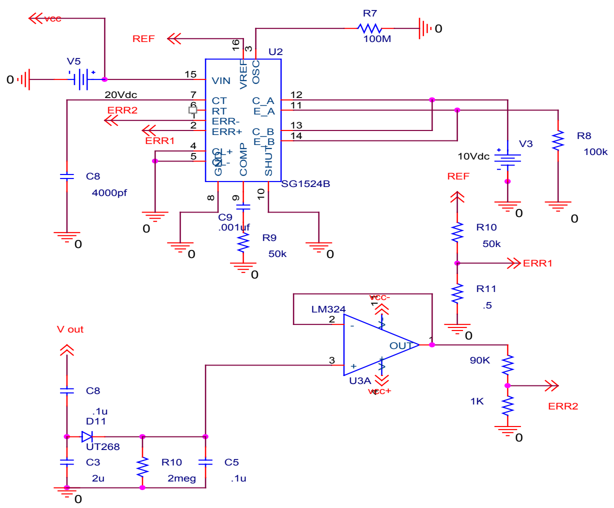
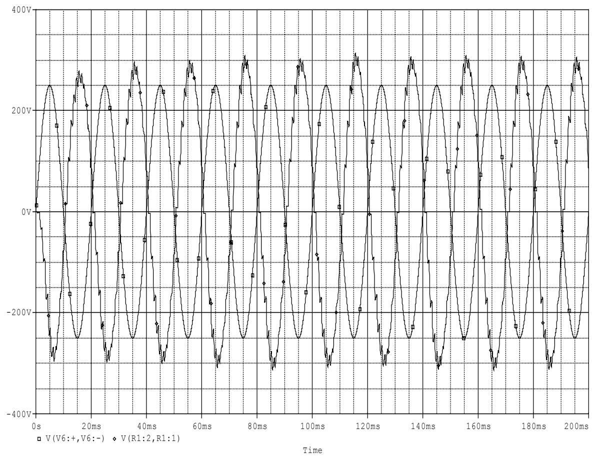


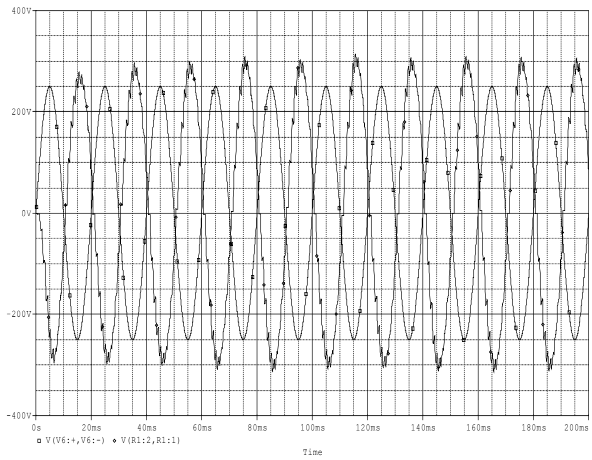
Fig. 4(b): AC Buck-Boost regulator control circuit by using SMPS.

3. RESULTS OF AC BUCK-BOOST CONTROLLER

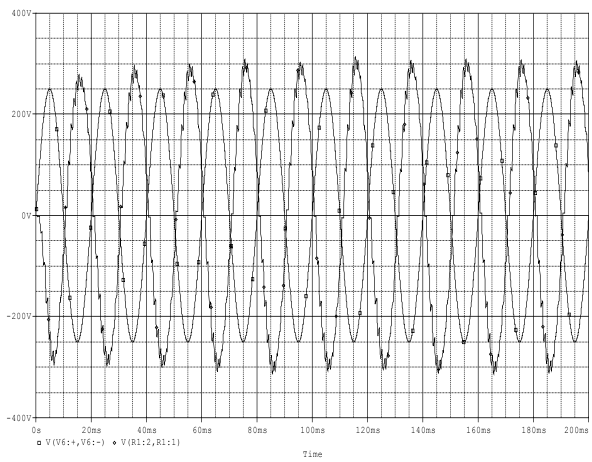
Figure 5 shows that as the pulse width of switching pulses are changed in an uncontrolled buck-boost ac voltage regulator, the output voltage can be varied widely from a lower than input voltage level to higher than the input voltage level. This feature can be utilized for automatic voltage regulation of the output of an ac buck-boost ac voltage regulator by feedback control similar to dc-dc switch mode power supplies. Results of automatic voltage regulation by control circuits of Figs.4(a) & 4(b) are shown in Figs 6 and 7. When input voltage is 250V and load is varied from 50 Ohms to 150 Ohms, it is seen that output is 300V as shown in Figs.6(a), (b) and (c), respectively. When input voltage is 400V and load is varied from 50 Ohms to 150 Ohms, it is seen that output is maintained at 300V as shown in Figs. 7(a), (b) and (c), respectively. From these results we can infer that the Buck-Boost AC voltage regulator with automatic control can maintain output voltage at load constant in both cases of input voltage variation and change in load. So, output voltage is always maintained at 300V corresponding to 220V rms. Typical input and output current waveforms of the proposed ac buck boost controller are shown in Fig.8. It is evident from this figure that due to high frequency switching small filters are adequate to make both currents sinusoidal as expected.



(a)

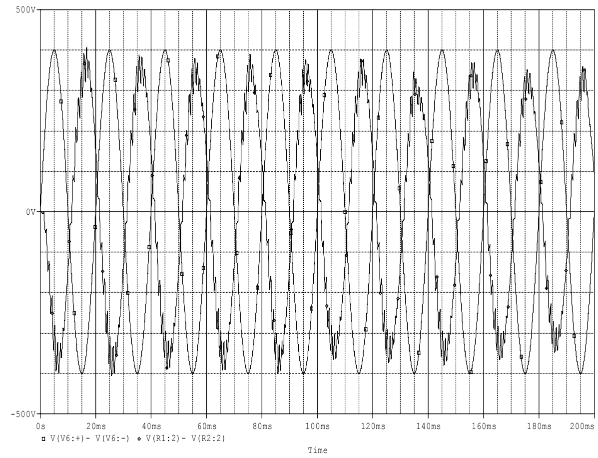


(b)

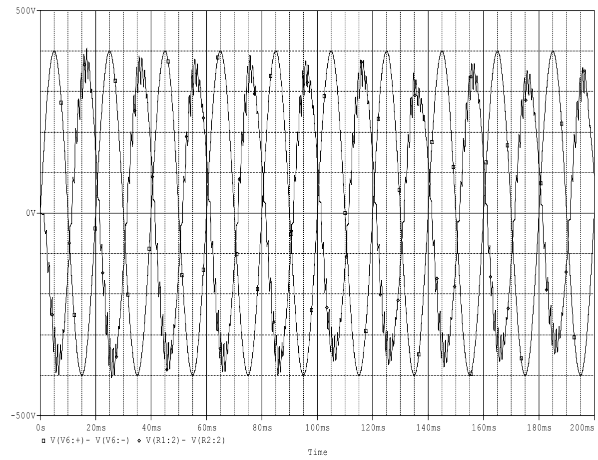


(c)

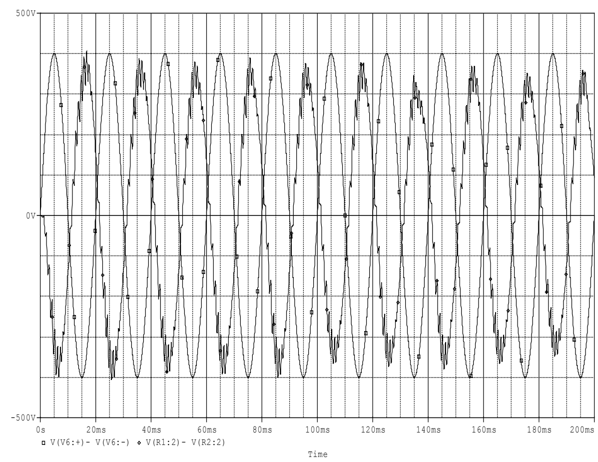
Fig. 6. Input- Output waveforms when input voltage = 250V and output voltage =300V: (a) load is 50 Ohms (b) load is 100 Ohms (c) load is 150 Ohms.



(a)



(b)



(c)

Fig. 7: Input- Output waveforms when input voltage = 400V and output voltage =300V: (a) load is 50 Ohms (b) load is 100 Ohms (c) load is 150 Ohms.

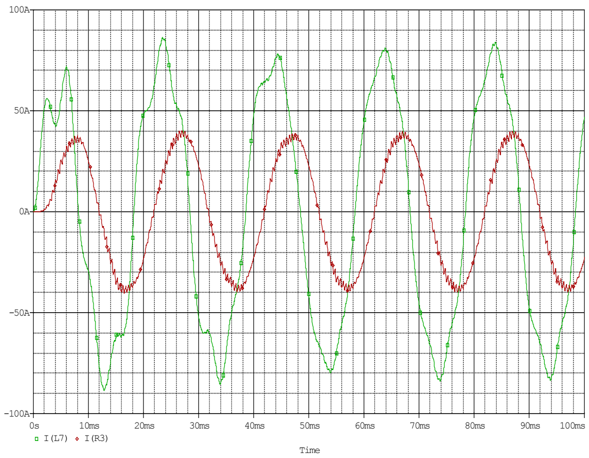


Fig. 8(a): Typical input and output current waveforms corresponding to results of Fig. 6(a).

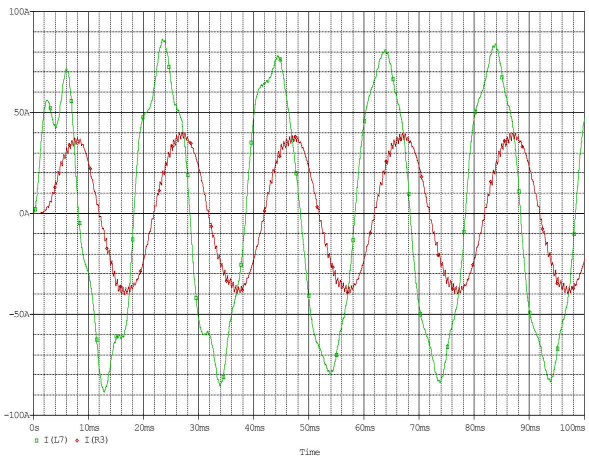


Fig. 8(b): Typical input and output current waveforms corresponding to results of Fig. 6(b).

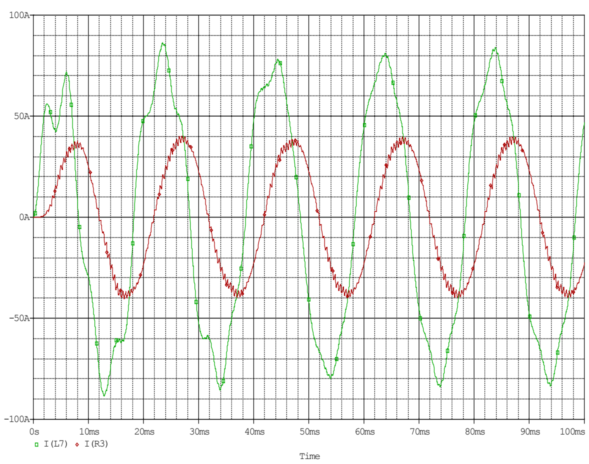


Fig. 8(c): Typical input and output current waveforms corresponding to results of Fig. 6(c).

4. CONCLUSION

The simulation results provided in this paper have illustrated the feasibility of the AC-AC switching voltage converter for voltage sag correction. The proposed AC-AC Buck-Boost Controller keeps the output voltage constant both for increase or decrease of input voltage and also during load changes.

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