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A BUCK - BOOST DC - AC CONVERTER: OPERATION, ANALYSIS, AND CONTROL.

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Abstract The main purpose of this paper is to analyze a four quadrant DC to AC switched mode inverter, using a buck-boost DC to DC converter. The buck-boost inverter is intended to be used in UPS design, whenever an AC voltage larger than DC link voltage is needed, with no need of a second power conversion stage. Operation, control strategy, simulation results are included in this paper.

I. Introduction

The conventional VSI (voltage source inverter) or buck inverter is probably the most important power converter topology. It is used in many different industrial an commercial applications. Among these applications, UPS and AC motor drives are the most important. One the characteristics of the buck inverter is that the instantaneous average output voltage is always lower that the input DC voltage.

The aim of this paper is to analyze a four quadrant DC to AC switched mode inverter, using buck-boost DC to DC converter, referred to as buck-boost inverter or buck-boost DC to AC converter [1]. The main attribute of this inverter topology is the fact that it naturally generates an AC output voltage lower or larger than the DC input voltage, depending on the instantaneous duty - cycle.

This property is not found in the classical voltage source inverter which produce an AC output instantaneous voltage always lower than the input DC voltage.

The buck-boost inverter is intended to be used in UPS design, whenever an AC voltage larger than DC link voltage is needed, with no need of a second power conversion stage.

II. Configuration of Power Stage

The power stage is configured on the current bi-directional buck-boost converter, which is shown in Fig. 1.a.

A circuit implementation of the buck-boost DC to AC converter is shown in Fig. 1b.

The buck-boost inverter achieves DC - AC conversion as follow: This buck-boost inverter is arranged for two bi-directional buck-boost converter. These converters produce a DC-biased sine wave output, so that each converter only produces an

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unipolar voltage. The modulation of each converter is 180 degrees out of phase with the other, which maximizes the voltage excursion across the load. The load is connected differentially across the converters. Thus, whereas a DC bias appears at each end of the load with respect to ground, the differential DC voltage across the load is zero. The generating bipolar voltage is solved by a push-pull arrangement. Thus, converters implementation need to be a current bi-directional.

For a buck-boost converter, by using the averaging concept, we obtain the following voltage relation for the continuous conduction mode:

$$\frac{V_1}{V_{in}} = \frac{D}{1-D} \tag{1}$$

where D is the duty cycle.

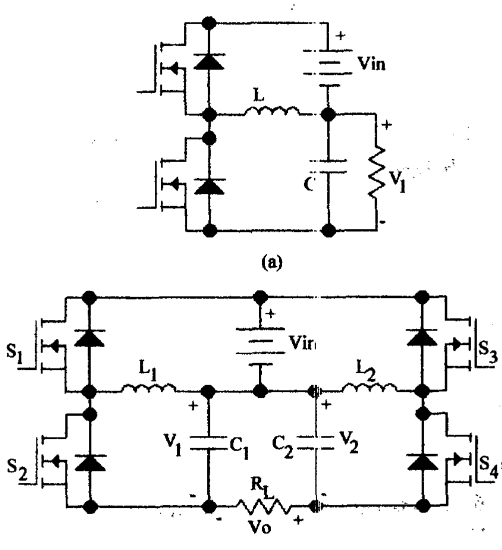

Fig. 1 (a) The current bi-directional buck-boost converter (b) The analyzed DC - AC buck-boost converter.

The voltage gain, for the buck-boost inverter, can be derived as follows: Assume that the two converters are 180 degrees out of phase. Then, the output voltage can be obtained as:

$$V_0 = V_1 - V_2 = \frac{V_{in}D}{1-D} - \frac{V_{in}(1-D)}{D} \tag{2}$$

$$\frac{V_o}{V_{in}} = \frac{2D-1}{D(1-D)} \tag{3}$$

The characteristic gain of the buck-boost inverter is shown in Fig. 2. It is interesting to note that the feature of zero output voltage is obtained for D = 0.5. If the duty cycle is varied around this point, then there will be an AC output voltage across the output terminal.

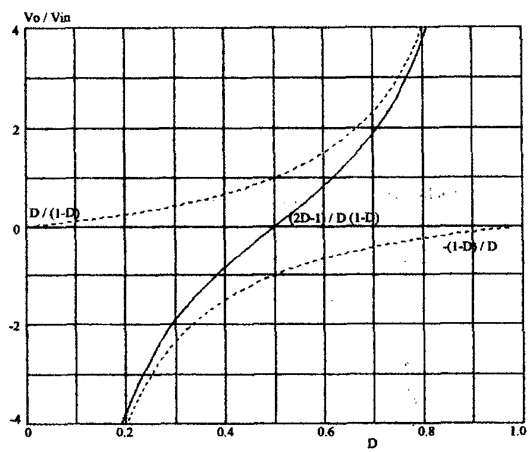

Fig. 2 DC gain characteristic.

III. Small - Signal Modeling and Control Aspects

The DC and Small-Signal performance of a buck-boost DC to AC converter is determined simply by substituting of circuit models (point by point) by the PWM switch, and analyzing the resulting linear circuits [2], [3]. These circuit models are shown in Fig. 3 for the DC and fundamental frequency. After determining the DC operating point, the output voltage/control transfer function is obtained.

Fig. 4 shows the equivalent circuit for the buck-boost inverter, with the three-terminal PWM switch.

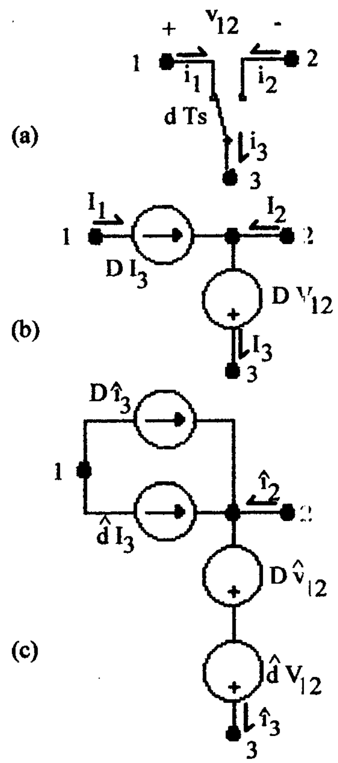

Fig. 3 (a) The PWM switch, (b) DC model and (c) Fundamental frequency model of the PWM switch.

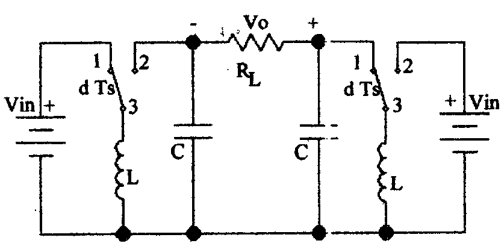

Fig. 4 The buck-boost inverter showing the PWM switches.

A.- DC Analysis

By substituting the DC model of the PWM switch into the buck-boost inverter of Fig. 4, results in the circuit of Fig. 5. In this circuit all the reactive elements have been shorted or opened as required at zero frequency.

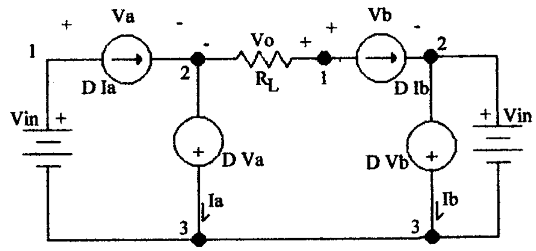

Fig. 5 DC model of the buck-boost inverter.

Analyzing the circuit shown in Fig. 5 we obtain the following equations:

$$\mathbf{V_a} = \frac{\mathbf{V_{in}}}{\mathbf{1-D}} \tag{4}$$

$$\mathbf{V_b} = -\frac{\mathbf{V_{in}}}{\mathbf{D}} \tag{5}$$

$$\mathbf{V_o} = \mathbf{V_{in}}\left(\frac{\mathbf{2D-1}}{\mathbf{D(1-D)}}\right) \tag{6}$$

$$\mathbf{I_a} = \frac{\mathbf{(2D-1)}}{\mathbf{D(1-D)^2}}\frac{\mathbf{V_{in}}}{\mathbf{R}} \tag{7}$$

$$\mathbf{I_b} = -\frac{\mathbf{(2D-1)}}{\mathbf{D^2(1-D)}}\frac{\mathbf{V_{in}}}{\mathbf{R}} \tag{8}$$

B.- Control to Output transfer Function

Fig. 6 shows the fundamental frequency model. It is determined by substituting the fundamental frequency model of the PWM switch into buck-boost inverter of Fig. 4. In this model, we are only considering disturbances in the duty cycle.

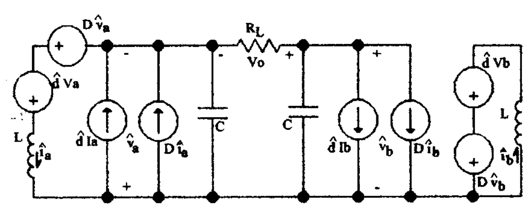

Fig. 6 Fundamental frequency model of the boost inverter.

Analyzing the circuit in Fig. 6 we obtain the following equations:

$$v_0 = v_a + v_b \quad (9)$$

$$v_a = -d[Za(S)] - v_0[Zb(S)] \quad (10)$$

where,

$$Za(S) = \frac{I_a SL - V_a(1-D)}{(1-D)^2 + S^2CL} \quad (11)$$

$$Zb(S) = \frac{SL}{R\left((1-D)^2 + S^2CL\right)} \quad (12)$$

$$v_b = -v_0[Zc(S)] - d[Zd(S)] \quad (13)$$

$$Zc(S) = \frac{1}{R\left(SC + D^2/SL\right)} \quad (14)$$

$$Zd(S) = \frac{DV_b + SLI_b}{SL\left(SC + D^2/SL\right)} \quad (15)$$

By substituting (10) and (13) into (9), the output voltage/control transfer function is obtained as:

$$\frac{v_0}{d} = \frac{-R(X_1S^3 + X_2S^2 + X_3S + X_4)}{Y_1S^4 + Y_2S^3 + Y_3S^2 + Y_4S + Y_5} \quad (16)$$

where,

$$X_1 = (I_a + I_b)CL^2 \quad (17)$$

$$X_2 = (DV_b + (D-1)Va)CL \quad (18)$$

$$X_3 = \left(I_aD^2 + I_b(1-D)^2\right)L \quad (19)$$

$$X_4 = \left((1-D)V_b - DV_a\right)(1-D)D \quad (20)$$

$$Y_1 = RC^2L^2 \quad (21)$$

$$Y_2 = 2CL^2 \quad (22)$$

$$Y_3 = RCL\left(1-2D+2D^2\right) \quad (23)$$

$$Y_4 = L\left(1-2D+2D^2\right) \quad (24)$$

$$Y_5 = RD^2(1-D)^2 \quad (25)$$

C.- Inverter Frequency Domain Analysis

Taking the following values for the components: L = 1.0 mH, C = 10 μF, R = 60 Ω and Vin = 100 V, the bode diagram for v_O/d can be obtained, using equation (16), as shown in Fig. 10.

It can be seen that the open loop system will be stable. However, due to the non-linearity of the buck-boost inverter, as in Fig. 2, the output voltage will no be sinusoidal.

For D greater than 0.5, using equation (16), the zeros locus of the open loop uncompensated system is in the right half plane, and the system presents a non minimum phase response. Non minimum phase systems are very difficult to control.

In order to make the output voltage pure sinusoidal, and to obtain stability for load changes, a controller should be introduced in the system.

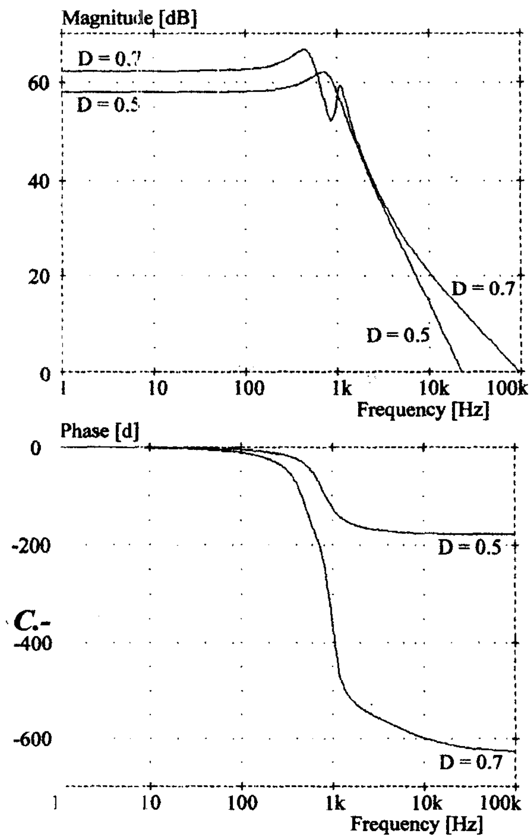

Fig. 10 Bode diagram of the open loop system, (for D = 0.5 and D = 0.7).

A PID controller is used to control de inverter to load changes. The Ziegler - Nichols tuning procedure was used to tune the controller.

IV. Simulation Results

The buck-boost DC - AC converter, in Fig. 1.b, was simulated using a computer simulation program. The following parameters were adopted in this simulation:

L1 = L2 = 1.0 mH
C1 = C2 = 10 uF
RL = 60 Ω
Vin = 100 V
Vo = 200 sin(2π 60 Hz)t
fs = 20 kHz

Fig. 8, 9, 10 and 11 shows simulated waveforms of the converter for the open loop system and resistive load.

In Fig. 8 for instance, the instantaneous AC voltage is 200 V, which means a r.m.s. value equal to 141 V. The processed power is 330 W

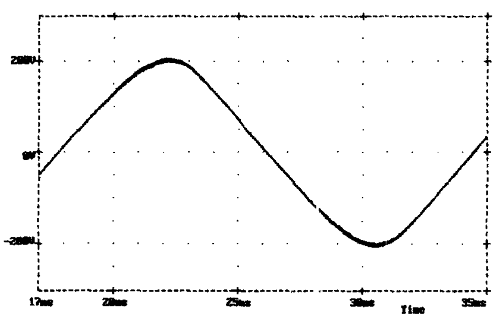

Fig. 8 Output voltage.

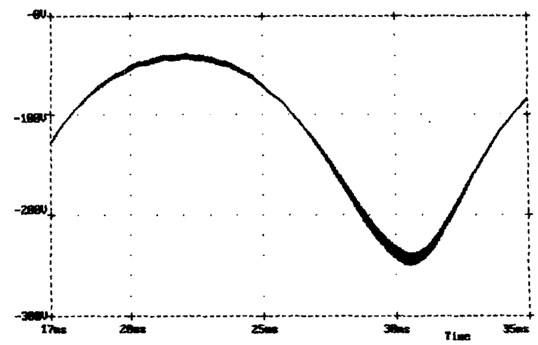

Fig. 9 Voltage of the capacitor C_1.

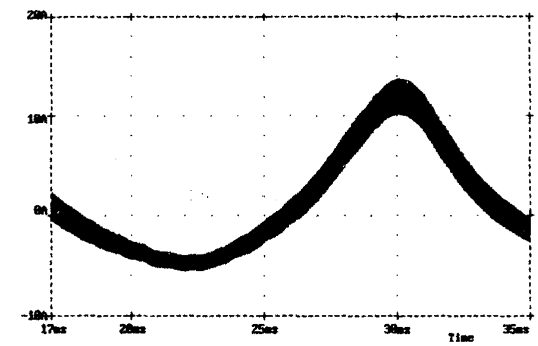

Fig. 10 Current of the inductor L_1.

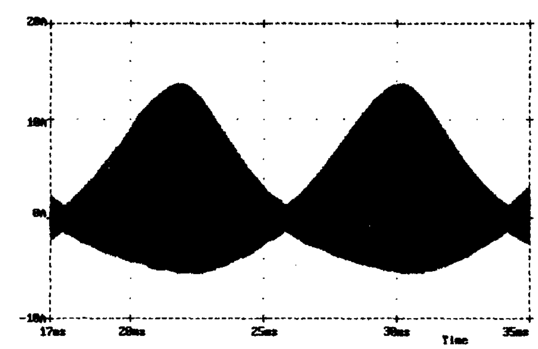

Fig. 11 Current of the power supply.

Figures 12, 13 and 14 shows the controller performance to load changes

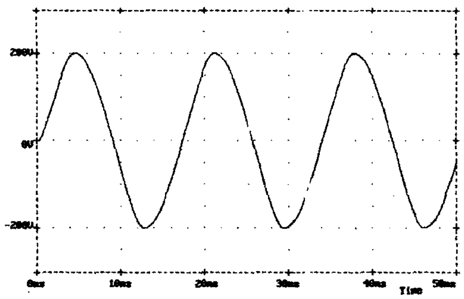

Fig. 12 Closed loop output voltage.
TDH = 3.35 %, Po = 330 W.

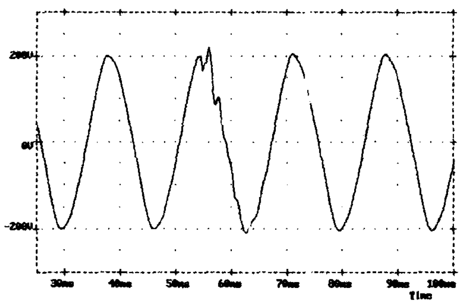

Fig. 13 Output voltage for a -30% step change in load, from 60 Ω to 42 Ω. TDH = 3.89%

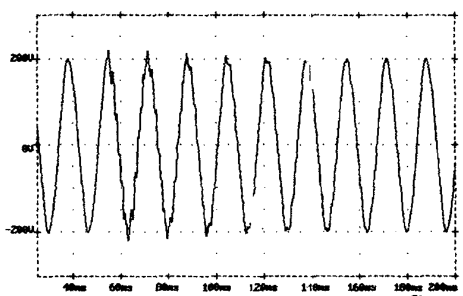

Fig. 14 Output voltage for a +30% step change in load, from 60 Ω to 78 Ω. TDH = 3.37%

Figures 12, 13 and 14 shows that the controller presents a very good performance for load changes. The TDH is less than 5 % giving good results. The problem is presented when we try to decrease the load above 80 Ω, the system is unstable. The problem can be solved using another kind of controller like variable structure, fuzzy, or passivity based control. As we know PID is a linear controller and if the process is nonlinear the initial tunings does not work for all the changes.

V. Conclusion

In this paper, we presented a brief analysis about the buck-boost DC - AC converter and example along with simulations.
In spite of the PID controller performance is good. It is suggested to use. Nonlinear controller to get better results when the load is decreased. An implementation of this inverter with different controllers will be tested.

VI. References

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