Development and Simulation of a Sine-PWM Boost Inverter for Telecommunication Applications

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Abstract: Telecommunication equipment require uninterruptible 48 V d.c. power supply obtained through battery bank, which are either charged from available utility grid/ installed diesel generator or from photovoltaic solar panel in remote areas. Conventionally, 230 V single phase a.c supply for other local loads like light, fan etc. at base transceiver stations (BTS) are derived from the 48 V d.c. bus using single phase inverter and subsequently stepping it up using a transformer operating at power frequency of 50 Hz. This transformer not only causes much loss in the system, but also requires large space and increases weight of the inverter. An alternative solution can be to boost the dc voltage level to 360 V and then obtaining 230 V a.c. supply using a single phase inverter. But, conventional boost converters can't obtain such a high voltage gain. To alleviate this problem, a single stage sine-pulse-width-modulated (SPWM) boost inverter is developed, analyzed and presented in this work. This inverter can directly obtain 230 V single phase a.c. supply from 48 V d.c. bus without any intermediate transformer, thereby, improving its efficiency and power-to-volume ratio. Performance of the inverter has been thoroughly investigated through computer simulation using MATLAB/Simulink with various types of loads and the simulated results were found in close agreement with the predicted behavior. Moreover, total harmonic distortion (THD) of output voltage has been found to be within permissible limit.

Keywords: Boost-inverter; power-to-volume ratio; Sine-PWM; THD; Voltage gain.

1 INTRODUCTION

Telecommunication applications require onsite d.c. and a.c. power supplies for various operations. Conventionally, 48 V d.c. supply supports telecom equipment, whereas 230 V, 50 Hz. Single phase a.c. supply operates auxiliary a.c. equipment, like lights, fans etc. Generation of 230 V ac supply using conventional single phase inverter [1, 2] requires input dc bus level of at least 360 V. Practical boost converters can't achieve such high gain to obtain 360 V from 48 V d.c. supply, due to the limitations of increased switching losses and large voltage stress across the switch. Two or more boost converters in cascade can help in achieving high voltage of 360 V from a d.c bus at 48 V, but with the cost of two-stage conversion loss and high initial cost of investment.

In recent years, many studies are therefore being carried out to generate single phase a.c. power supply of 230 V from 48 V d.c. with total harmonic distortion (THD) within acceptable limit. Various

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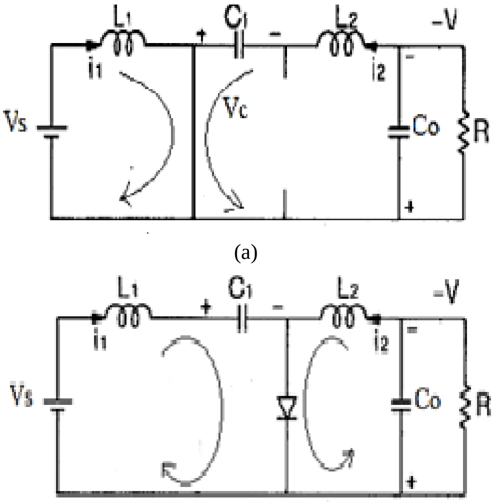
power supplies [3-5] have been suggested to meet the demands of telecom applications. The paper [3] described charging a 48 V battery bank for telecommunication applications from a photovoltaic solar panel using a soft-switched dc-dc converter. The inverter suggested in [4] can directly generate a.c. supply form PV solar panel. A single phase grid-connected inverter presented in [5] can be used for photovoltaic system in remote areas. However, the two-stage power conversion suggested in this paper will cause in large power loss and this is the main drawback of this system. Conventional inverters use Sine pulse width modulation (SPWM) control technique [8]-[9] to minimize the THD, thereby reducing the size of filter components.

In this paper, a single phase boost inverter has been developed based on the four quadrant operation of Cuk converter [7]. In order to reduce the THD at the output, bipolar-SPWM control technique has been adopted. This inverter uses four switching devices (IGBT) and converts a 48V d.c. voltage to 230V a.c. voltage without any intermediate transformer or any boost converter at the input for voltage step up. This inverter therefore, enjoys the advantages of higher efficiency, minimum number of switches, reduced weight and volume of the filter components. This inverter can also find wide applications in solar/battery (d.c.) power to utility line (a.c.) power conversion, variable speed d.c. or a.c. motor drives, switching power supplies, uninterruptable power supplies etc.

2 CUK CONVERTER AND ITS OPERATION

The Cuk converter [6] is a of dc-dc converter, output voltage magnitude of which can be greater or less than the input voltage magnitude. Polarity of output voltage of Cuk converter, as shown in Fig. 1, is opposite to that of the input voltage. The Cuk converter has various advantages of high efficiency and continuous input and output current with less ripple content. The main disadvantage of this converter is the requirement of an additional inductor and a capacitor.



(a)

(b)

Fig. 2. Equivalent circuit of cuk converter during (a) on interval and (b) off interval.

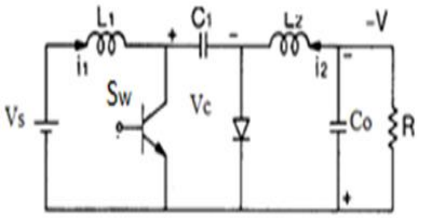


Fig. 1. Basic circuit of CUK converter.

When the switch (S_w) is turned on, current flows through the inductor (L_1) and provides a charging path for L_1 through the switch (S_w). At the same time the coupling capacitor (C_1),charged to the polarity as shown in Fig. 2(a) from the previous cycle discharges through the output inductor (L_2) thereby feeding energy to the output and also increases the energy stored in the output inductor (L_2) .The diode being reverse biased remains in OFF condition.

When the switch (S_w) turns off, C_1 is charged by the input inductor current (i_1) through the forward biased diode (D) as shown in Fig. 2(b). At the same time the inductor (L_2) will also discharge the stored energy through the output.

3 FOUR-QUADRANT OPERATION OF CUK CONVERTER

A four-quadrant Cuk converter [7] as shown in Fig. 3 is a bidirectional power converter as it allows power flow either from source to load or from load to source depending on circuit condition. Polarity of output voltage can also be positive or negative depending on whether the duty ratio is less than or greater than 0.5. As the polarity of both voltage and current can be positive or negative, an a.c. supply can be obtained at the output together with bidirectional power flow. Therefore, a four-quadrant Cuk converter can be used as an inverter.

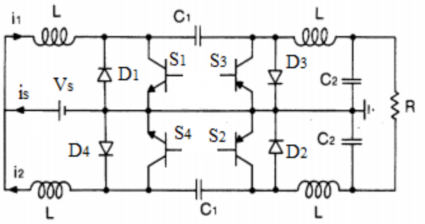


Fig. 3. Four-quadrant CUK converter.

4 SINUSOIDAL PULSE WIDTH MODULATION (SPWM)

In this method of modulation, a sinusoidal reference signal of frequency (f_r) is compared with a triangular carrier signal of frequency (f_c) and gate signals are generated at the output of the comparator as shown in Fig. 4.

When sinusoidal wave has magnitude greater than the triangular wave, switch (S_+) turns ON and when the magnitude of sinusoidal wave is less than that of the triangular wave, the bottom rail switch (S_-) is ON, as shown in Figs. 5 and 6. Here, the width of each pulse is varied in proportion to the amplitude of the reference sine-wave and several pulses per half-cycle of reference signal are used to control the rms value of output voltage. The main advantage of this modulation technique is that, total harmonic distortion (THD) of output voltage is minimized.

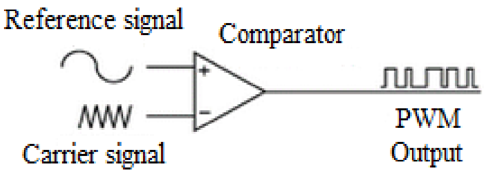


Fig. 4. Schematic circuit for comparison of reference and carrier signals.

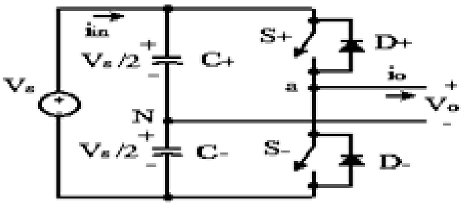


Fig. 5. Schematic of a single phase half- bridge inverter.

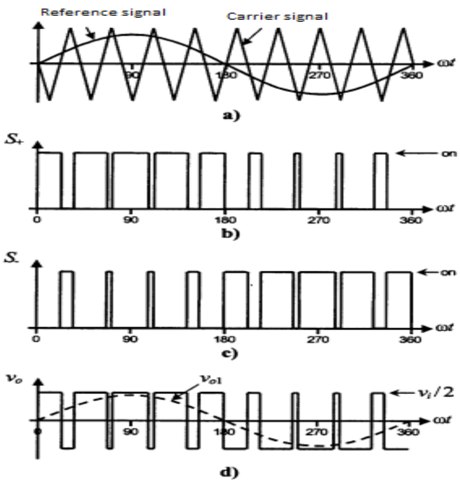


Fig. 6. Waveform of (a) carrier and reference signal (b) gate pulse of switch s+ (c) gate pulse of switch s- and (d) a.c. Output voltage.

5 DEVELOPMENT OF SINGLE PHASE BOOST INVERTER

The schematic representation of the single phase boost inverter developed from four quadrant Cuk converter has been shown in Fig. 7. The inverter uses four IGBTs with anti parallel diodes to facilitate bidirectional power flow. Emitters of left leg IGBTs are referenced to the negative terminal of the source, whereas, collectors of right leg IGBTs are referenced to the negative terminal of the source. Same gate pulses are applied to the gates of S_1 and S_2 and their complementary gate pulses are applied to S_3 and S_4.

6 SIMULATION OF SINGLE PHASE BOOST INVERTER

In order to investigate the performance of the proposed single phase SPWM boost inverter as shown in Fig. 8, a thorough computer simulation has been carried out with Matlab/simulink with rated specification and designed parameters as per Table 1.

The frequency of triangular carrier signal is selected to be 10 kHz and its peaks are fixed at -1 and +1 respectively. The switching device, here IGBTs being minority carries device, suffer from the drawbacks that they have current tail at turn-off. Hence, for safe operation of IGBTs the maximum duty cycle is required to be maintained within 90%.

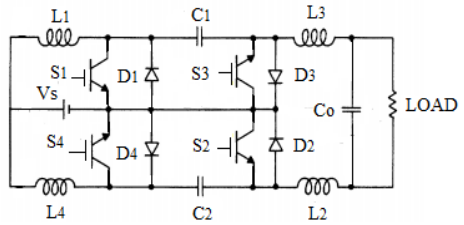


Fig. 7. Scheme of single phase boost inverter.

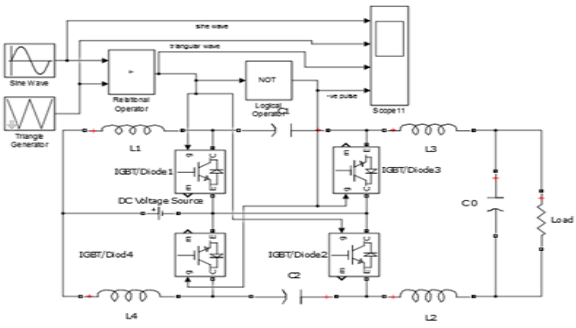


Fig. 8. Simulation circuit of SINE-PWM boost inverter.

6.1 Derivation of Modulating Signal Amplitude

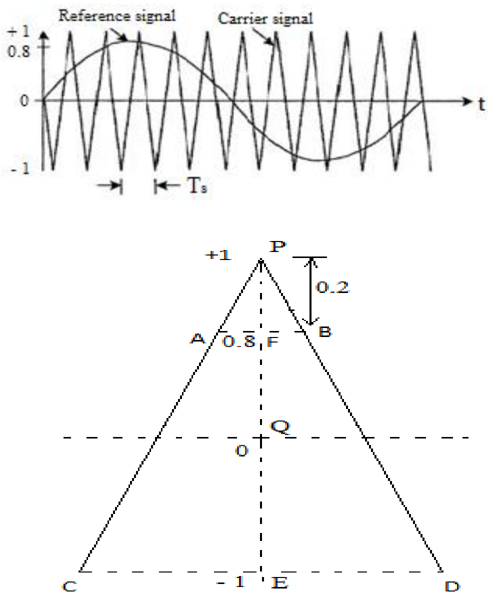


Fig. 9. Derivation of modulating signal amplitude.

From Fig. 9

$$\frac{AB}{CD} = 0.1$$

$$\text{or, } \frac{AF}{CE} = 0.1$$

From similar triangles, ΔPAF and ΔPCE

$$\text{We get, } \frac{PF}{PE} = \frac{AF}{CE} = 0.1$$

or, PF = 0.2 [as, PE = 2]

So, QF = Amplitude of modulating sine wave

or, QF = QP - FP

or, QF = 1 - 0.2

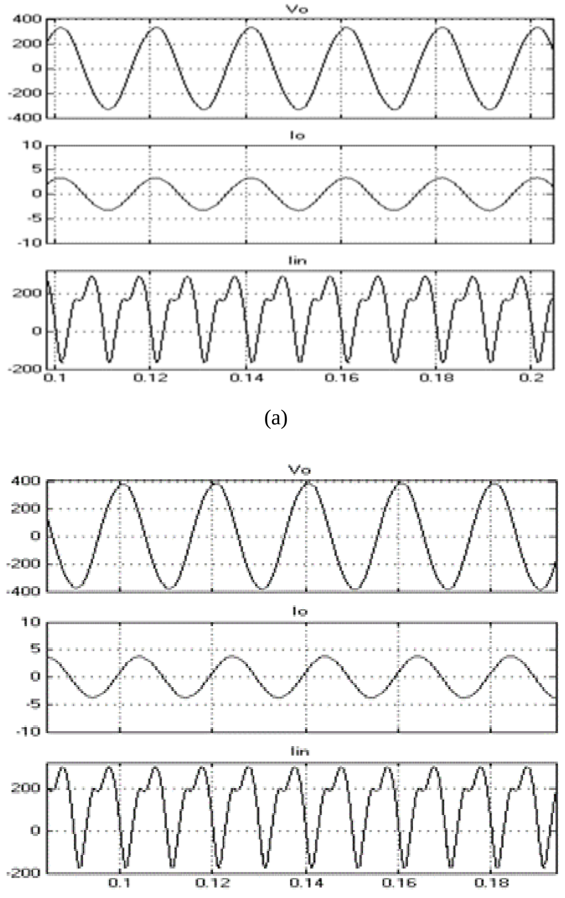
Hence, QF = 0.8

Table 1. Specification and rating of major components.

Specifications	Rated input voltage supply = 48 V Rated a.c. output voltage = 230 V Rated output power = 500 watt Switching frequency = 10 kHz
Major components	Input inductor, $L_1 = L_4 = 500$ µH Output inductor, $L_2 = L_3 = 10$ mH Coupling capacitor, $C_1 = C_2 = 0.5$ mF Rated output capacitor, $C_0 = 503$ µF IGBT voltage and current stress: 287 V, 324 A

Therefore, in order to get maximum and minimum duty cycle of 90% and 10% respectively, the amplitude of modulating signal has been set equal to 0.8 as derived in following section.

Simulated results, showing output voltage, output and input current for a purely resistive load of 500 watt are depicted in Fig. 10(a). Simulation has also been carried for a resistive-inductive load with load impedance of 100∠67° ohm. The simulation results, showing output voltage, output and input current for the inductive load is also depicted in Fig. 10(b). From the results, it is clearly seen that with an input voltage of 48 V, the output peak voltage has been stepped up to the value of 330 V i.e. arms value of 230 V single phase a.c supply is obtained at the output. Fast Fourier Transform (FFT) analysis for verification of output voltage quality has also been carried out and the results are shown in Fig. 11. It is observed that THD at the output is only 2.5 % i.e. well within permissible limit.



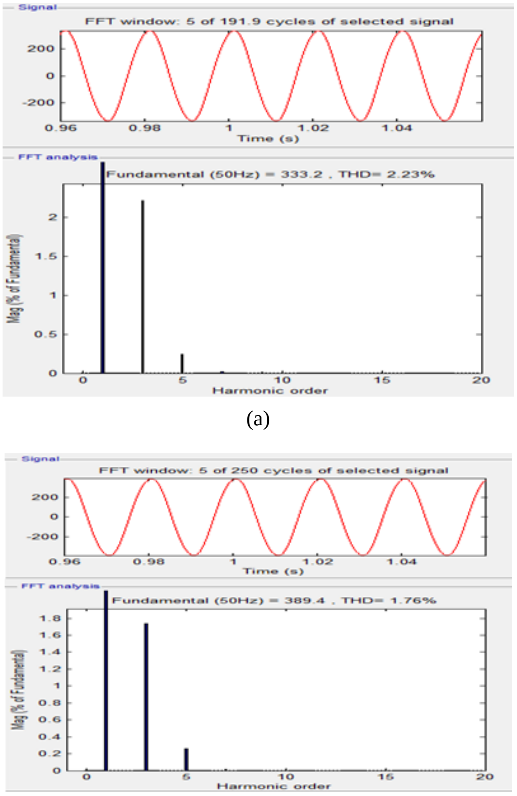
(a)

(b)

Fig. 10. Waveforms of output voltage (V_0), output current (I_0) and input current (I_{in}) with (a) resistive and (b) resistive-inductive load.

7 CONCLUSION

In this paper, a single phase boost bipolar SPWM inverter using only four switches has been suggested for telecommunication applications. The performance of the inverter has been tested with computer simulation using MATLAB/simulink and



(a)

(b)

Fig. 11. FFT analysis of boost inverter output voltage waveforms with (a) resistive and (b) resistive-inductive load.

the results are found in close agreement with the predicted behavior.

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