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Active Buck-Boost Inverter for Inverter Fed Induction Motor Applications

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Abstract-This concept presents a new isolated soft-switching bidirectional buck-boost inverter for fuel cell applications. The buck-boost inverter combines an isolated DC-DC converter with a conventional inverter to implement buck-boost DC-DC and DC-AC conversion. The main switches achieve zero voltage switching and zero current switching by using a novel synchronous switching SPWM and the volume of the transformer in the forward and fly-back mode is also minimized. This inverter is suitable for wide input voltage applications due to its high efficiency under all conditions. An active clamping circuit reduces the switch's spike voltage and regenerates the energy stored in the leakage inductance of the transformer; therefore, the overall efficiency is improved. This concept presents the operating principle, a theoretical analysis and design guidelines. This can be extending by using Induction motor fed air conditional application.

Keywords: buck-boost, ZVS, SPWM, Induction Motor

I INTRODUCTION

Nowadays the demand for air conditioner has grown significantly. So the amount of power consumption in houses and offices has increased rapidly mainly because of a change in the current lifestyles. In particular, power consumption is dominant in the summer season when the supply of electricity is tight. Thus, it is clear that the maximization of air conditioner efficiency can lead to significant energy saving. The traditional air conditioners regulate temperature by switched on or switched off entirely. It is done by using a compressor. Inverter air conditioners have a variable frequency drive that incorporates an adjustable electrical inverter to control the speed of the motor and thus the compressor and cooling output. [1]-[3]

The inverter air conditioner uses a rectifier to convert the incoming alternating current to direct current and then uses an electrical inverter to produce AC of a desired frequency. The variable frequency AC drives an induction motor. And the line voltage is varying in a wide range [4],[5]. Inverter control is used towards the reduction of power consumption of the electrical air conditioner.

For the power conversion of dc-ac there are different types of inverters, like voltage source inverter, current source inverter etc. They perform either buck or boost conversion. To overcome these limitations of only voltage buck conversion, or voltage boost conversion a number of modifications have been developed. Z-source inverter [6] employs an impedance network for connecting the power source main converter and the load. ZSI allows shoot through of the inverter switches. ZSI has a diode and an "X"-shaped impedance network between the dc source and the inverter. A one stage buck–boost inverter without a line frequency step-up transformer [7], has an isolated transformer to step up the voltage, this structure increases the system volume, weight, and cost. The diode-assisted buck–boost VSI can perform a wide-range buck-and-boost conversion with additional passive and active elements [8], has a unique X-shaped diode capacitor network. The switched boost inverter is introduced with the Z source inverter and less inductors and capacitors [9], is composed of an active switch and diode. SBI has only one *L-C* pair which leads significant reduction in the size, weight and cost. The boost factor of SBI is (1-D) times that of ZSI it is the major drawback of SBI. In Trans-Z-source inverter, [10] the entire impedance network consist of a capacitor and transformer, it reduces the voltage stress.

Switched inductor quasi Z source inverter, [11] has more number of inductors, capacitors, diodes and reduced passive components. These types of inverters create a double stage cascade structure. It is very complex and difficult to control. The cascade structure has low efficiency and stability.

The previous solutions introduce additional transformer or passive components to boost its voltage, which means reduced system compact and expensive cost. To overcome the problems of traditional solutions in buck–boost inverters, this thesis presents an active buck–boost inverter (ABI) and its control method. "Active Boost Network," is used to boost the voltage in ABI circuit. ABI performs the voltage buck and boost conversion in a quasi-single-stage inverter, and has the advantages of compact structure, improved power density, and efficiency. In a control system, a sensor monitors the system output and feeds the data to a controller that adjusts the control to maintain the desired system output. A closed loop control has high reliability, easy implementation and output short circuit and overload protection.[21]-[25]

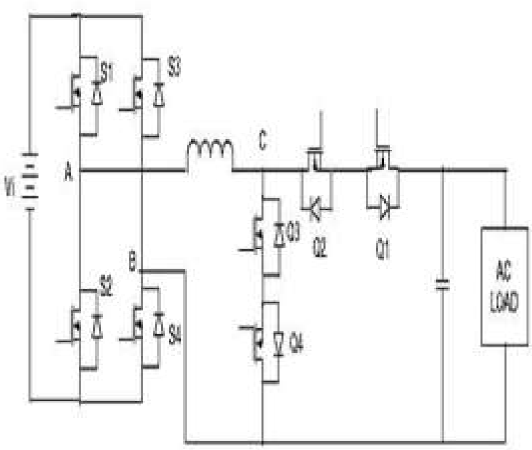

Fig.1 Active buck–boost full-bridge inverter.

II NEW TOPOLOGY

The proposed inverter topology. The ac/ac unit performs the boost operation, which is composed of active switches only. And the buck operation is realized with the help of full bridge switches. Both the units sharing the same inductor and capacitor. Only one power processing stage is exists in the proposed topology; thus it can be seen as a quasi-single-stage buck-boost inverter.

III OPERATING PRINCIPLE

The proposed inverter consists of two modes of operation. One is the buck mode and the second is the boost mode. For buck operation sinusoidal pulse width modulation is applied on the full bridge switches, and the fundamental output voltage of the bridge is noted as,

$$V_{AB\_F} = MV_t sin\omega t \tag{1}$$

Where *M* is the modulation ratio; the SPWM voltage is boost by the ac/ac unit, while sharing the same inductor with the dc/ac unit. The equivalent input voltage of the ac/ac unit can be represented as V_{AB_F}, and the operating principle of the ac/ac unit is the same as the boost ac/ac converter.

The output voltage of the ac/ac unit is given by,

$$V_0 - \frac{V_{AB\_F}}{1-d} - \frac{MV_t sin\omega t}{1-d} \tag{2}$$

where *d* is the duty ratio of *Q*3 (positive half-cycle) or *Q*4 (negative half-cycle); representing (1 − *d*) with *d'*, i.e., *d'* is the duty ratio of *Q*1 (positive half-cycle) or *Q*2 (negative half cycle), we can obtain

$$\frac{V_0}{V_t} = \frac{Msin\omega t}{d'} \tag{3}$$

As can be seen, the output voltage can be modulated with two parameters: *M* and *d'*, and the ac/ac unit.

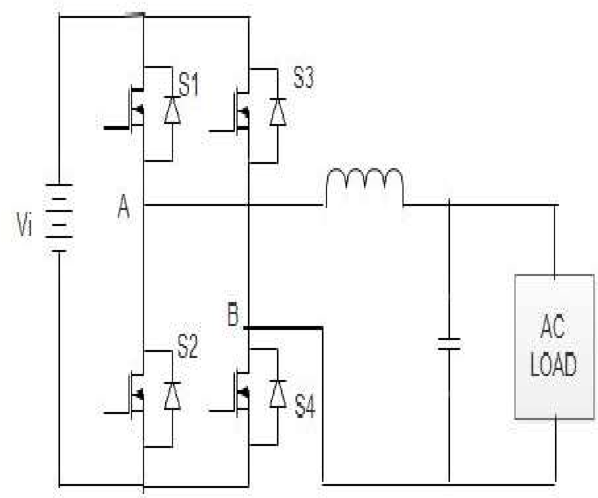

Fig.2. Equivalent circuit of the ABI in the buck mode.

1 Buck Mode

When the input voltage is high enough to get the desired output, the ABI operates in the buck mode to realize the voltage step down. In this condition, *d'* is set to 1; therefore, *Q*1 and *Q*2 are always turned on, while *Q*3 and *Q*4 are switching in line frequency. The equivalent circuit of the ABI is the VSI, as shown in Fig.2.

SPWM schemes can be adopted with,

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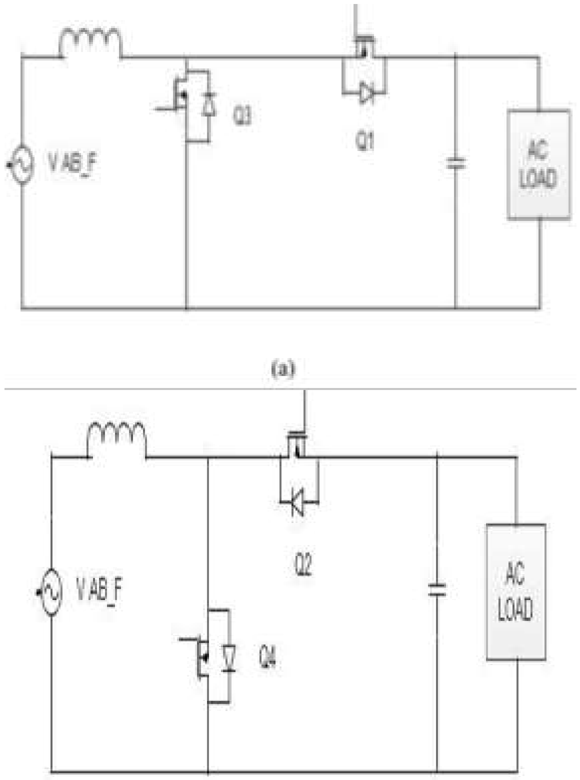
$$V_0 = MV_t sin\omega t \tag{4}$$

2 Boost Mode

When the input voltage is low and not enough to get to the desired output, the ABI operates in the boost mode. In this condition, M is set to 1, d' is adjusted to boost the voltage; the output voltage can be calculated as

$$V_0 = \frac{V_t sin\omega t}{d'} \tag{5}$$

In the output positive half-cycle, *Q*2 and *Q*4 are always on, while *Q*1 and *Q*3 are modulated in complementary, as shown in Fig. 3(a). In the output negative half-cycle, *Q*1 and *Q*3 are always on, while *Q*2 and *Q*4 are modulated in complementary, as shown in Fig. 3(b). SPWM schemes are adopted to modulate S1−S4, whereas Q1−Q4 are modulated the same as in the boost ac–ac converter discussed earlier. With a unipolarity SPWM scheme, in the positive half-cycle, the bridge output voltage VAB is varied with Vi and 0, whereas the voltage after the inductor VCB is varied with Vo and 0.



(b)

Fig. 3 Equivalent circuit of the ac/ac unit. (a) Output positive half-cycle (b) Output negative half-cycle.

3.4 DESIGN

The design of the proposed inverter is done at a power level of 1.5 KVA aiming at high power applications such as inverter air conditioner. The required output voltage is 230V. Various parameters of the inverter have been designed accordingly.

$$Z = R_L + jX_L \tag{6}$$

$$Z = 2\pi f L_f \tag{7}$$

$$Z = \frac{1}{2\pi f C_f} \tag{8}$$

IV. INDUCTION MOTOR (IM)

An induction motor is an example of asynchronous AC machine, which consists of a stator and a rotor. This motor is widely used because of its strong features and reasonable cost. A sinusoidal voltage is applied to the stator, in the induction motor, which results in an induced electromagnetic field. A current in the rotor is induced due to this field, which creates another field that tries to align with the stator field, causing the rotor to spin. A slip is created between these fields, when a load is applied to the motor. Compared to the synchronous speed, the rotor speed decreases, at higher slip values. The frequency of the stator voltage controls the synchronous speed. The frequency of the voltage is applied to the stator through power electronic devices, which allows the control of the speed of the motor. The research is using techniques, which implement a constant voltage to frequency ratio. Finally, the torque begins to fall when the motor reaches the synchronous speed. Thus, induction motor synchronous speed is defined by following equation,

$$n_s = \frac{120f}{P}$$

Where f is the frequency of AC supply, n, is the speed of rotor; p is the number of poles per phase of the motor. By varying the frequency of control circuit through AC supply, the rotor speed will change.

A. Control Strategy of Induction Motor

Power electronics interface such as three-phase SPWM inverter using constant closed loop Volts l Hertz control scheme is used to control the motor. According to the desired output speed, the amplitude and frequency of the reference (sinusoidal) signals will change. In order to maintain constant magnetic flux in the motor, the ratio of the voltage amplitude to voltage frequency will be kept constant. Hence a closed loop Proportional Integral (PI) controller is implemented to regulate the motor speed to the desired set point. The closed loop speed control is characterized by the measurement of the actual motor speed, which is compared to the reference speed while the error signal is generated. The magnitude and polarity of the error signal correspond to the difference between the actual and required speed. The PI controller generates the corrected motor stator frequency to compensate for the error, based on the speed error.

V SIMULATION RESULTS

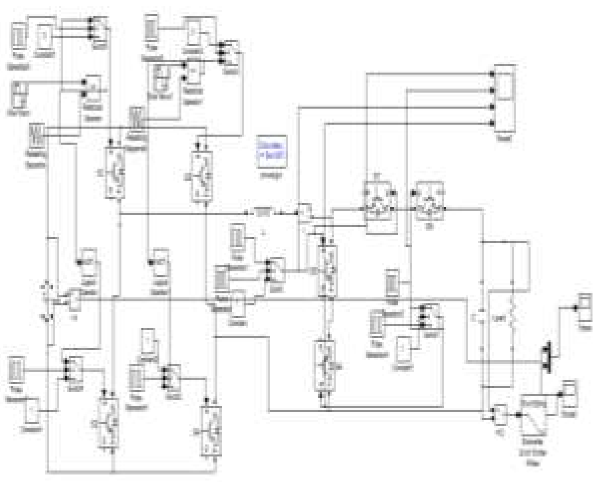


Fig 4 shows the Matlab/Simulink model of proposed converter in Boost mode 120V as input

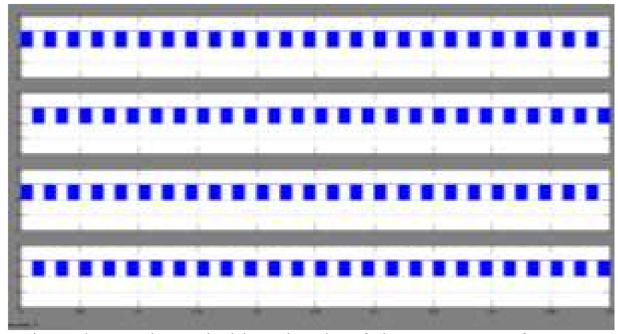


Fig 5 shows the switching signals of the converter of Q1-Q4

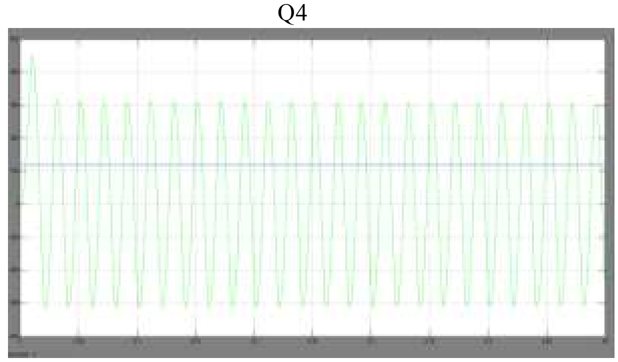


Fig 6 shows the input & output voltages of the proposed converter in boost mode Vin=120V

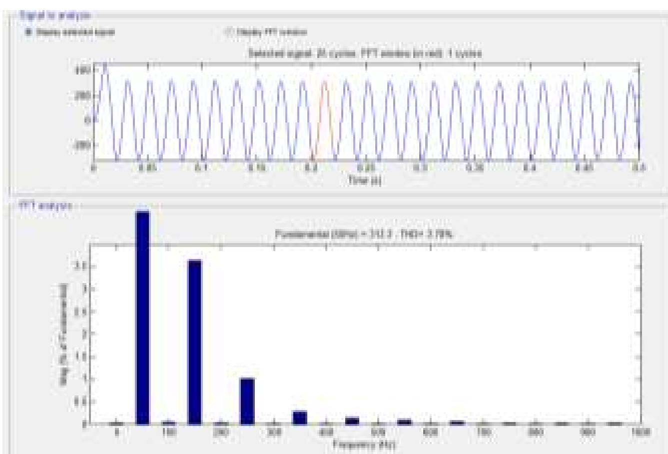


Fig 7 shows the THD analysis of proposed boost converter voltage

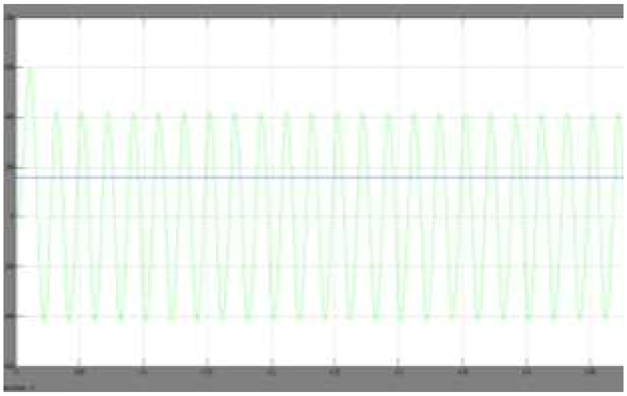


Fig 8 shows the input & output voltages of the proposed converter in boost mode Vin=160V

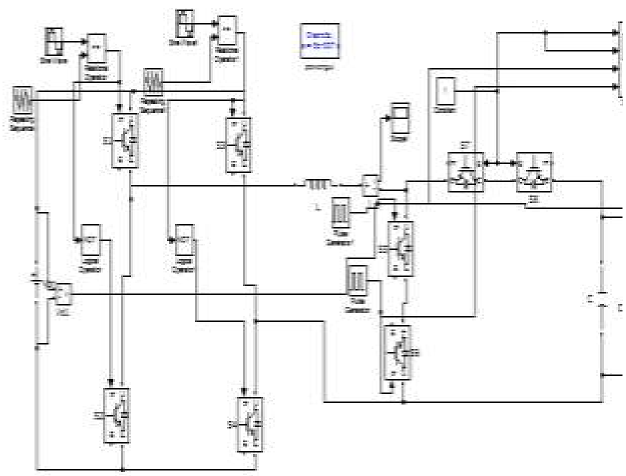


Fig 9 shows the Matlab/Simulink model of proposed converter in Buckmode 250V as input

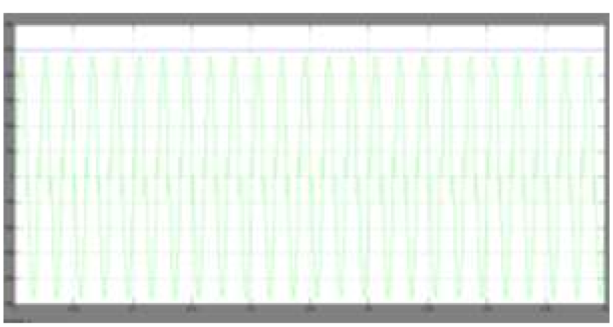


Fig 10 shows the input & output voltages of the proposed converter in buck mode Vin=250V

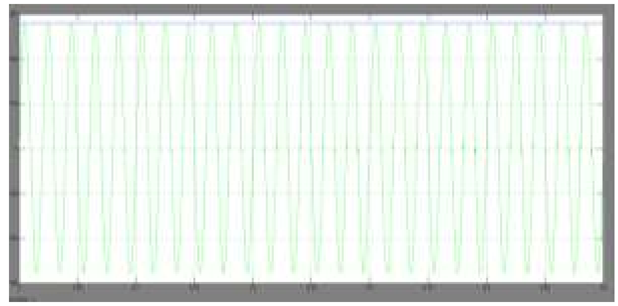


Fig 11 shows the input & output voltages of the proposed converter in boost mode Vin=280V

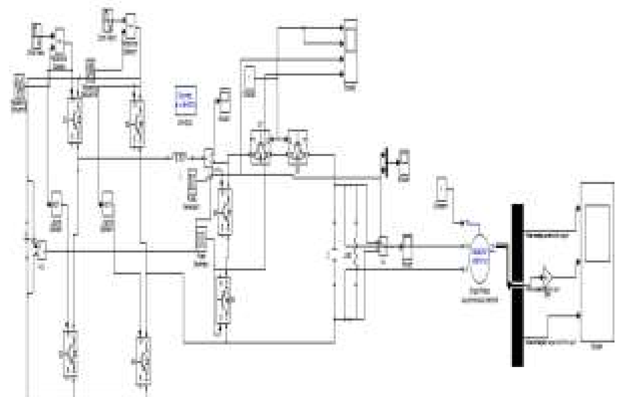


Fig 12 shows the Matlab/Simulink model of proposed converter with Induction motor

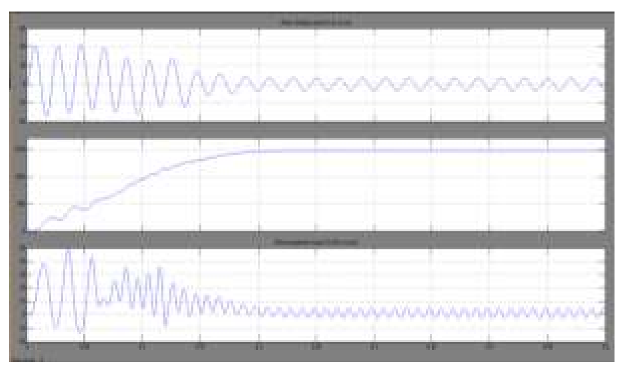


Fig 13 shows the performance of induction motor system

VI. CONCLUSION

This paper has suggested a new active buck-boost inverter which is suitable for inverter air conditioner applications. This inverter achieves both buck and boost mode of operation with a wide range of input. The boost ac-ac unit performs the voltage boost mode. This control scheme achieves good voltage regulation. It is useful in reducing system volume, increasing the system efficiency, reducing the cost and also increasing the system power density. The simulation results of buck and boost modes of operation are developed. This result shows that the ABI can operate in both buck and boost mode. The proposed concept is further connected to induction motor system and performance of the system is observed.

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