Scientific Journal Impact Factor (SJIF): 1.711
International Journal of Modern Trends in Engineering and Research
ISSN (ONLINE) : 2349 - 9745
ISSN (PRINT) : 2393 - 8161

Design of Active Buck Boost Inverter for AC applications

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Abstract— In this paper, the soft-switching ac-link ac–ac buck–boost converter will be studied in more detail. This single-stage converter, which is, in essence, an extension of the dc–dc buck–boost converter, can be an excellent alternative to dc-link converters. Being a buck–boost converter, this converter is capable of both stepping-up and stepping-down the voltage. The link current and voltage are both alternating, and their frequency can be as high as permitted by the switches and the sampling time of the microcontroller. This eliminates the need for dc inductors or dc electrolytic capacitors, and the main energy storage element is an ac inductor (L). Moreover, in this converter, galvanic isolation can be provided by adding a single-phase high-frequency transformer to the link. Therefore, the proposed converter is expected to be more compact compared to the conventional dc-link converter. The other advantage of this converter is the soft switching of the switches, which is feasible by adding a small capacitor (C) to the link. In this paper, the design and analysis of this converter will be studied in detail. In order to accurately analyze this converter, the effect of the LC link resonance on the performance of the converter will be studied. This analysis helps in evaluating the performance of the converter at low power levels when the resonating time of the LC link is not negligible. Using this analysis, the link peak current and the link frequency may be calculated at any point of operation. The accuracy of this method is verified through simulations and experiments. Detailed comparison of the proposed converter with the dc-link converter will be also presented in this paper. It will be shown that, despite having more switches, the current rating of the switches is lower in this converter. Moreover, the efficiencies of the two converters will be compared. Finally, the performance of the soft-switching ac-link ac–ac buck–boost converter is experimentally evaluated in this paper. It will be shown that the converter has the possibility of changing both the frequency and the voltage. Both step-up and step-down operations will be verified through simulation.

Keywords- AC–AC converter, ac-link, buck–boost converter, galvanic isolation

I. INTRODUCTION

Three phase ac–ac converters are needed in a variety of applications, including wind power generation and variable-speed drives. Different types of ac–ac converters have been proposed over the years. These converters can be classified as direct or indirect depending on their power conversion type. Matrix converters and cyclo converters are examples of the direct ac–ac converters, whereas the dc-link and ac-link converters are classified as indirect ac–ac converters. Cycloconverters and matrix converters have several limitations that hinder their widespread use in industry. Among these limitations is the poor input displacement, low input power factor (PF), and limited output frequency in the cycloconverters, and the low output to input voltage ratio in the matrix converters. The dc-link converters are the most common type of ac–ac converters. This type of converters is formed by a three-phase boost rectifier and a three-phase buck inverter. Regardless of the type of the rectifier or the inverter, dc electrolytic capacitors are integral part of these converters. Electrolytic capacitors are very sensitive to temperature and can cause severe reliability problems at higher temperatures. Therefore, converters that contain dc electrolytic capacitors have higher failure rates and shorter lifetimes compared to the other converters. This is not the only problem with dc-link converters. In these converters, galvanic isolation can be provided by three-phase low-frequency transformers. Therefore, another limitation of the dc-link converters is the large size and the heavy weight of the low-frequency transformers employed. Resonant ac–ac converters, which are classified as ac-link converters, have been proposed as an alternative to dc-link converters In, the parallel ac voltage resonant converter was proposed. The link in this converter is formed by a parallel *LC* pair resonating continuously. Therefore, the passive link components need to have high reactive ratings, and there is high power dissipation in the link. Moreover, the load inductance and capacitance can affect the link resonance. Hence, this type of converter is not suitable for all types of loads. Despite the superficial resemblance between the parallel ac voltage link converter proposed in and the proposed configuration here, the principles of operation of the two converters are totally different. In the link is resonating all of the time, whereas in the proposed converter, the link resonates just for a short portion of time in each cycle.

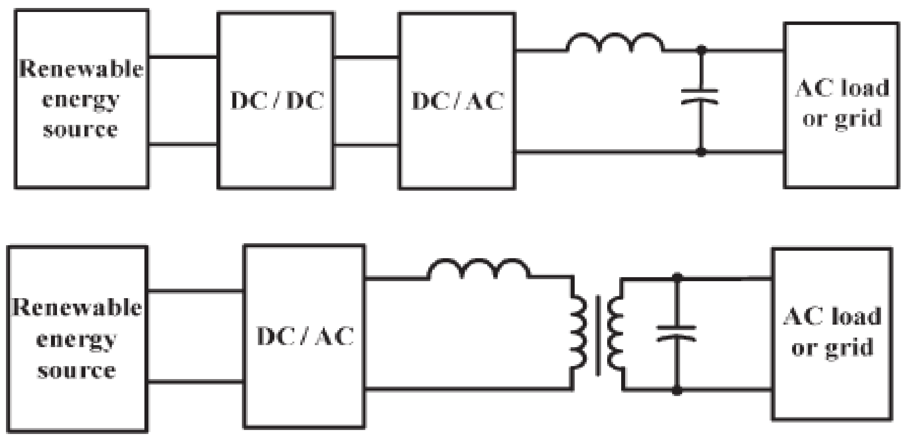


Fig.1. Existing buck boost inverter schemes

Therefore, in both the link capacitor and the link inductor are required to allow the converter to operate properly, while in the proposed configuration, the link capacitor may be removed, and the converter can still operate. Apparently, no soft switching is offered when the capacitor is removed. The link current and voltage are both sinusoidal because the link resonates continuously. However, in the proposed configuration, the link current is triangular, and the link voltage is close to a square wave. In the parallel ac voltage link converter proposed in the terminals need to appear as current sources; therefore, inductors are placed at the terminals. However, in the proposed converter, similar to a buck–boost converter, we need voltage sources across the terminals. Other than the aforementioned configurations, several other three-phase ac–ac topologies have been proposed. Two of them, which have led to the proposed configuration and are both classified as dc-link converters, are studied here. A hard-switching ac–ac buck–boost converter was proposed. This converter was an extension of the dc–dc buck–boost converter and was formed by 12 unidirectional switches. The link inductor current in this converter was dc, and the switches had hard switching. A partial resonant topology with 12 unidirectional switches was proposed. This converter was a soft-switching dc link ac–ac buck–boost converter. Despite the high frequency of the link and the soft switching, this converter suffers from reduced utilization of the inductor due to the dc component of the link current and also long quiescent resonant swing back time during which no power is transferred. In this paper, a soft-switching ac-link ac–ac buck–boost converter is introduced, studied, analyzed, and evaluated. In this converter, the link current and voltage are both alternating, and their frequency can be very high. This eliminates the need for the dc electrolytic capacitors and the low-frequency transformers. In case galvanic isolation is required, a single-phase high frequency transformer may be added to the link. The alternating link current and the short resonating modes of this converter solve the problems associated with the converter proposed. This topology was originally proposed and the present authors of this paper studied the principles of operation and different applications of this converter. the application of this converter in photovoltaic power generation was studied, and the performances of the dcto-ac and hybrid dc-to-ac configurations were experimentally evaluated. This paper, on the other hand, focuses on the design and analysis of the single phase ac–ac configuration, especially the effect of the resonance on the performance of the converter at low power levels. Although the analysis of this converter was studied, the proposed procedure was not experimentally verified. This paper evaluates the performance of the ac–ac converter through both simulations and experiments. The detailed experimental results corresponding to the ac–ac configuration are presented in this paper. As will be shown, an important feature of this ac–ac converter is the capability of the converter to control the input PF. This feature will be verified here. Moreover, the efficiencies and the switch current ratings of this converter and the dc-link converter are compared in this paper. These two converters have not been compared before.

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 paper presents an active buck–boost inverter (ABI) and its control method. The ABI can boost the voltage with "Active Boost Network," 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 without utilization of a line-frequency transformer and additional passive elements.

II. ACTIVE BUCK BOOST INVERTER

The Fig. 2 shows the general structure of the single-stage buck– boost inverter derived in Fig. 1.

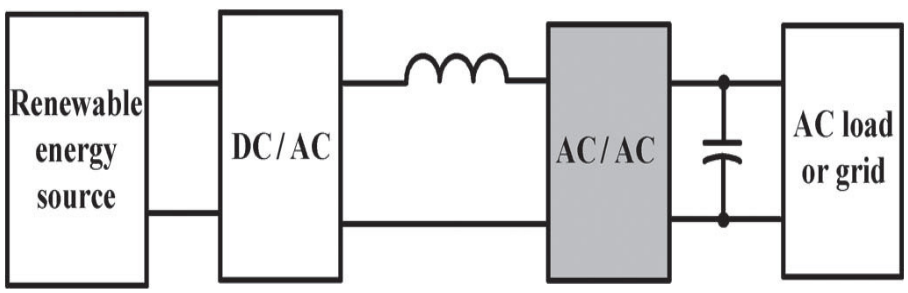


Fig.2. Structure of Active buck boost inverters

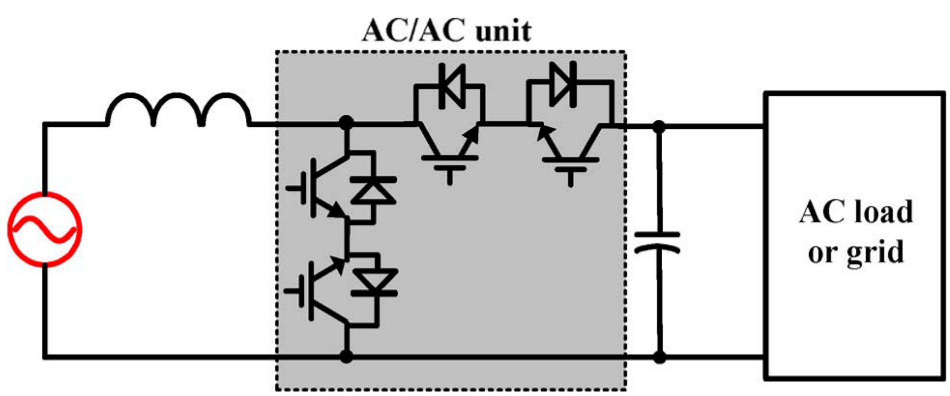


Fig.3. Boost active inverter

The step-up transformer is replaced by the "ac/ac" stage to perform voltage boost function. The "ac/ac unit" can reach the voltage boost conversion, whereas the dc/ac unit performs the voltage buck conversion. The boost ac/ac converter is utilized as the ac/ac unit here, as shown in Fig. 3

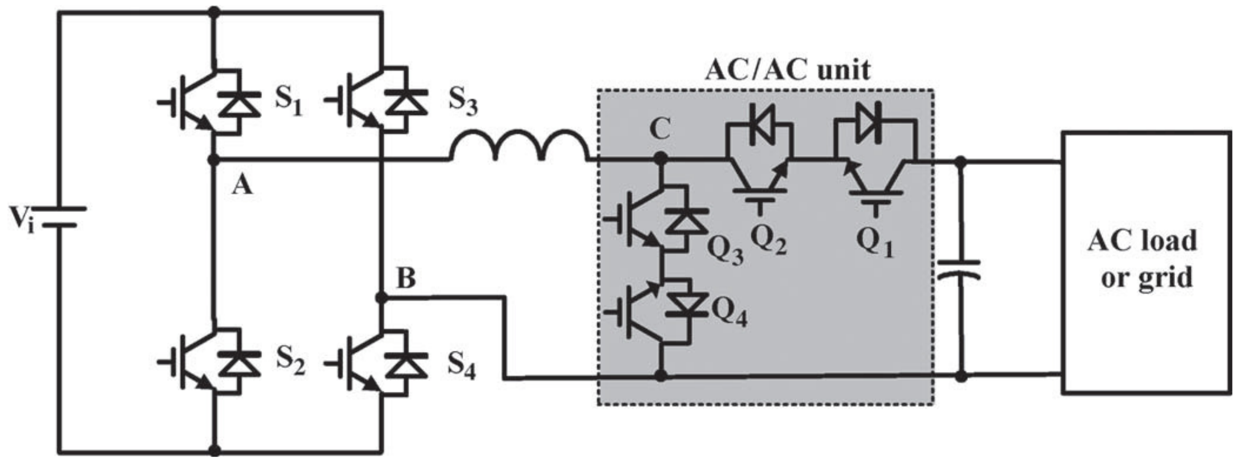


Fig.4. Proposed active buck boost inverter

Then, a novel single-stage buck–boost full-bridge inverter is derived, as shown in Fig. 5. The voltage boost function is realized with the inserted ac/ac unit composed of active switches only, which is Named the ABI. As can be seen, the dc/ac and ac/ac units share the inductor and capacitor in the ABI, thus avoiding additional passive elements. Only one power-processing stage exists in the proposed topology; thus, it can be seen as a quasi-single-stage buck–boost inverter. be applied in the full-bridge switches, and the fundamental voltage of the bridge output voltage vAB can be expressed as

$$v\text{AB\_F} = MVi \sin \omega t \quad (1)$$

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.

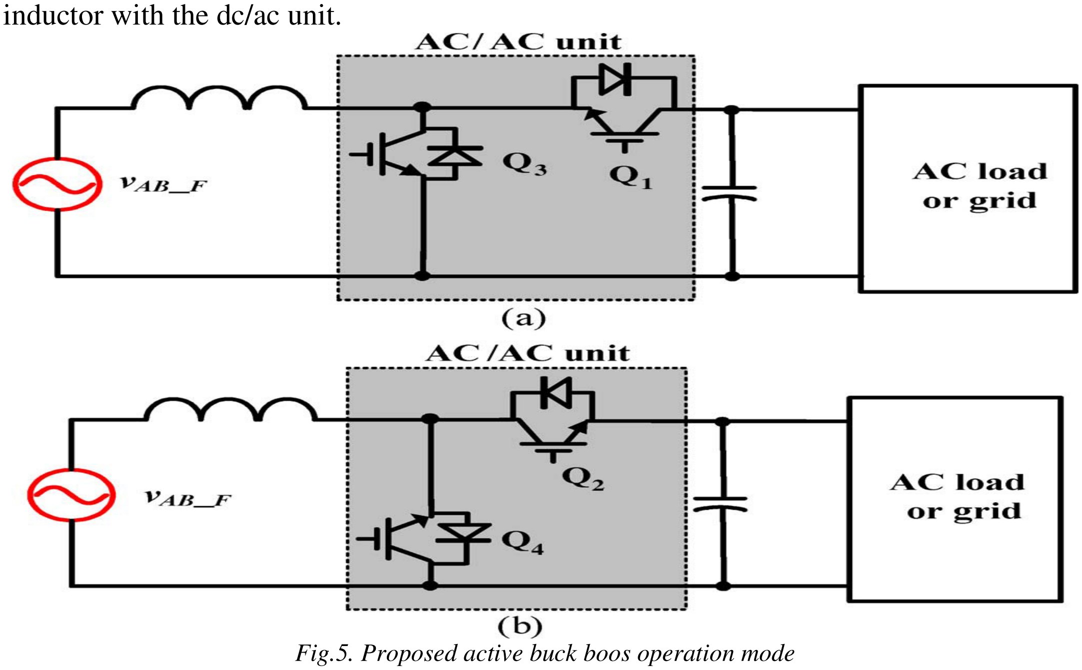


Fig.5. Proposed active buck boos operation mode

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, $Q1$ and $Q2$ are always turned on, while $Q3$ and $Q4$ are switching in line frequency.

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. 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. The voltage across the inductor uL can be the following four cases: 0, Vi, $-vo$, and $Vi - vo$. The condition in the negative half-cycle is similar, and the voltage across the inductor can be the following four cases: 0, $-Vi$, $-vo$, and $-Vi - vo$. The four operating modes in the positive half-cycle. In the positive half-cycle, $Q2$ and $Q4$ are always turned on.

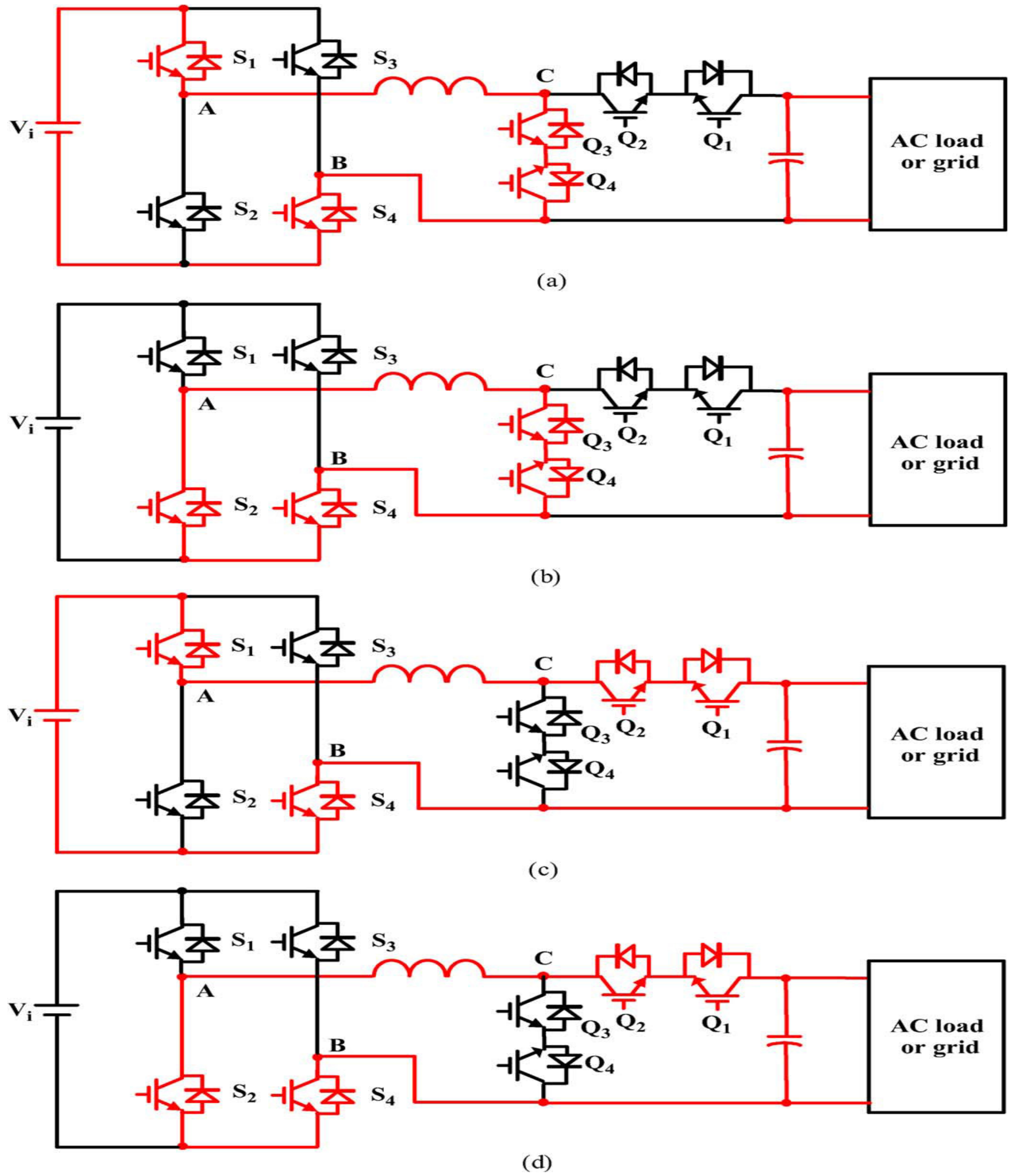


Fig.6. Proposed active buck boos operation mode of operation

In Mode I, $S1$, $S4$, and $Q3$ are turned on, and uL is equal to Vi. The inductor current is charged by the input power source.

In Mode II, $S2$, $S4$, and $Q3$ are turned on, and uL is equal to 0. The inductor current is in the freewheeling state.

In Mode III, $S1$, $S4$, and $Q1$ are turned on, and uL is equal to $Vi - vo$. The inductor current increases when $Vi > vo$, whereas it decreases when $Vi < vo$.

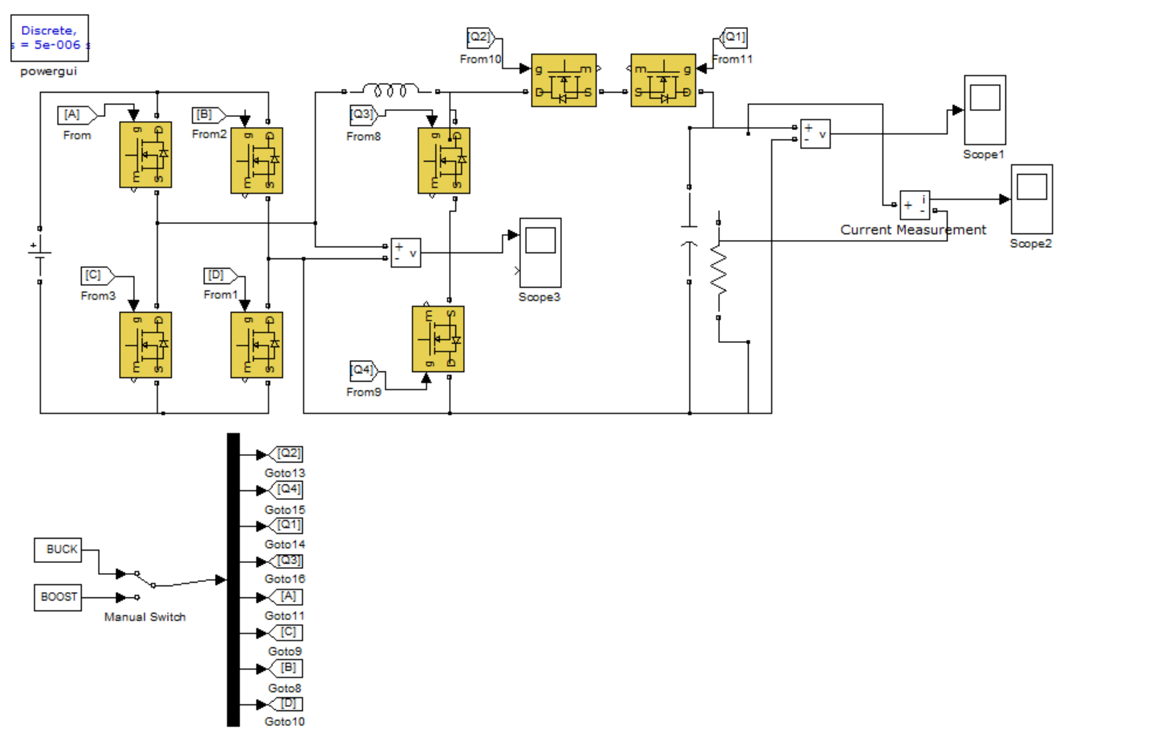
In Mode IV, $S2$, $S4$, and $Q1$ are turned on, and uL is equal to $-vo$. The inductor current decreases.

The three of the four operating modes exist in one switching cycle, according to the relationship between Vi and vo. When $Vi > vo$, the modulation wave $Vd\_$ is used to generate duty ratio $d\_$, and the modulation wave VSPWM is used to generate the SPWM signal. In this condition, $Vd_ > V$SPWM; the three operating modes are Mode II, Mode III, and Mode IV. When $Vi < vo$, the switching state is described. In this condition, $Vd_ < V$SPWM; the three operating modes are Mode I, Mode II, and Mode III. In this converter, the average current control method is used. The switches corresponding to each input phase are turned off when the average of the unfiltered current in that phase meets the average of its reference, and once this happens, the average of the current in that phase and also the average of the reference current corresponding to that phase will be both reset. Similarly, the output-side switches are turned off when the average of the unfiltered phase currents meets their references (mode 5) or when there is just enough energy left in the link to allow the link voltage to swing.

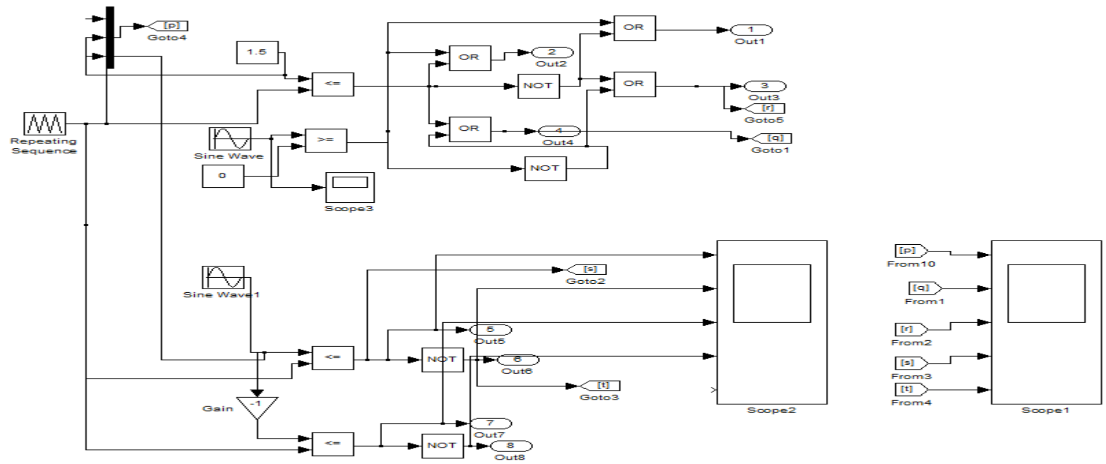
The switching signals of $Q1-Q4$; "+"represents the on state,"−"represents the off state, and "d" and "$d\_$" represent the duty ratio in the switching cycle. When in the buck mode, which means that the input voltage Vi is larger than the peak output voltage Vop, in the positive half-cycle, $Q1$, $Q2$, and $Q4$ are turned on, and $Q3$ is turned off, whereas in the negative half-cycle, $Q1$, $Q2$, and $Q3$ are turned on, and $Q4$ is turned off. When in the boost mode, which means that the input voltage Vi is less than the peak output voltage Vop, in the positive half-cycle, $Q2$ and $Q4$ are turned on, and $Q1$ and $Q3$ are switched in complementary with high frequency, whereas in the negative half-cycle, $Q1$ and $Q3$ are turned on, and $Q2$ and $Q4$ are switched in complementary with high frequency.

III. SIMULATION RESULTS

To verify the feasibility of the proposed strategy, simulations are carried out.



BUCK MODE



BOOST MODE

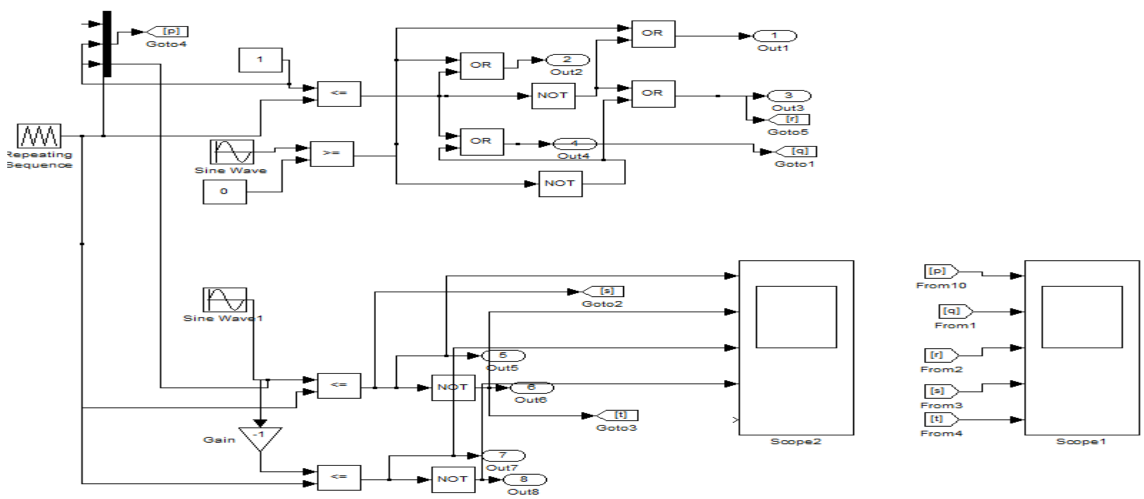


Fig.7. Proposed system Simulink diagram

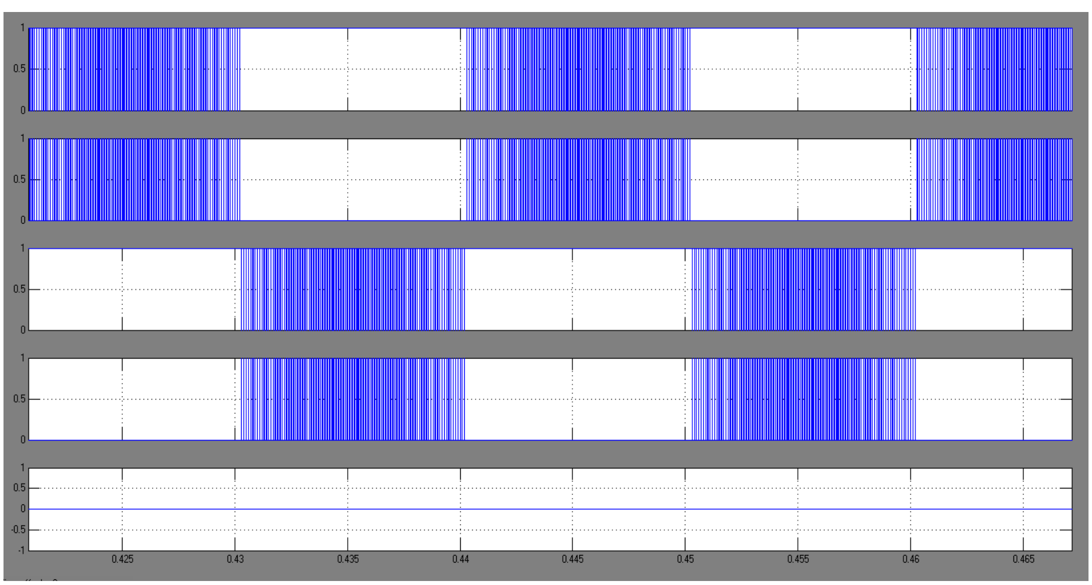


Fig.8. PWM pulses to the inverter

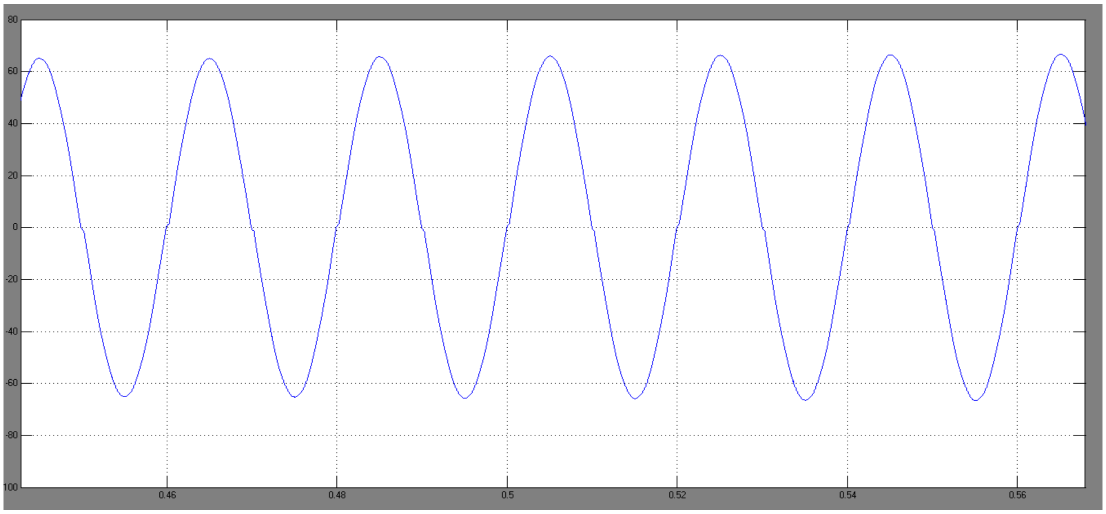


Fig.9. Output voltage in buck mode

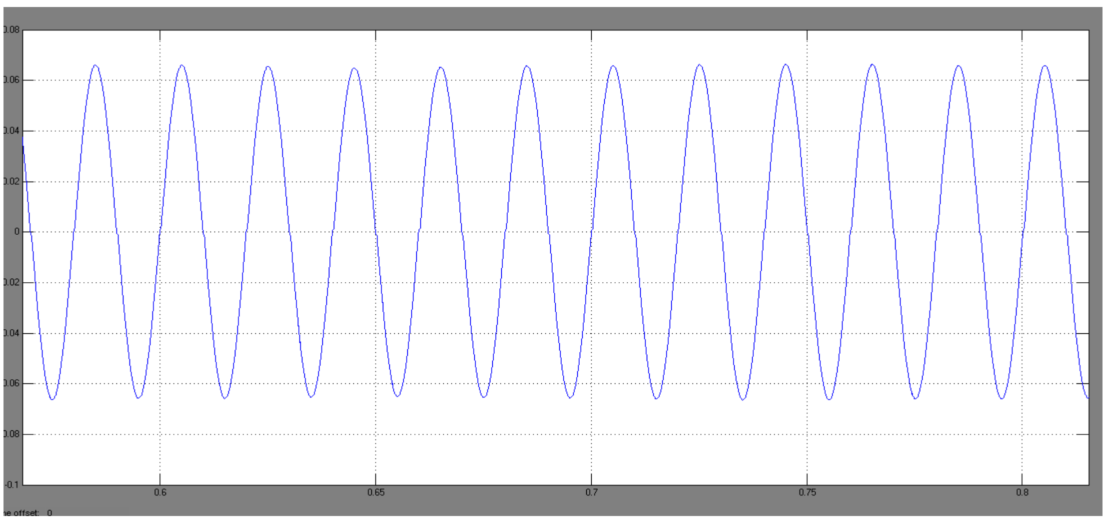


Fig.10. Output current in buck mode

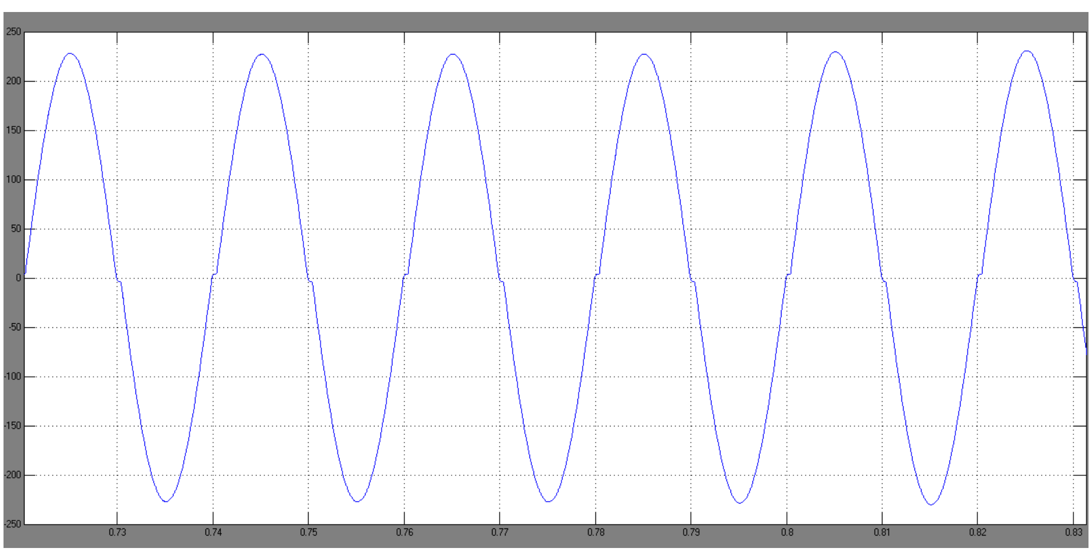


Fig.11. Output voltage in boost mode

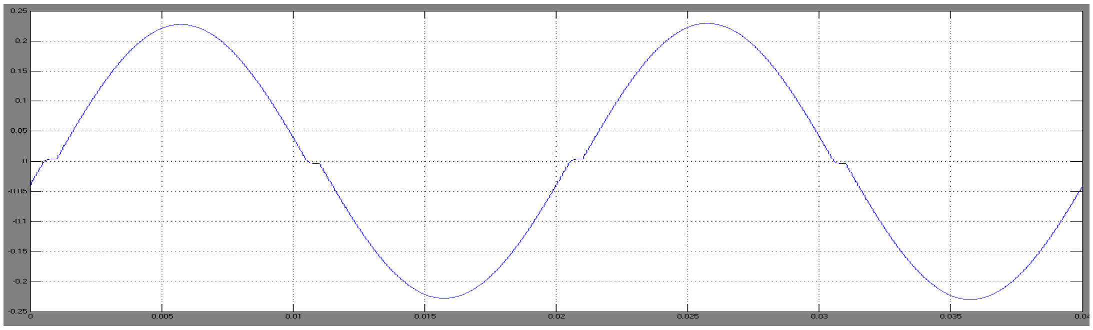


Fig 12. Output current in boost mode

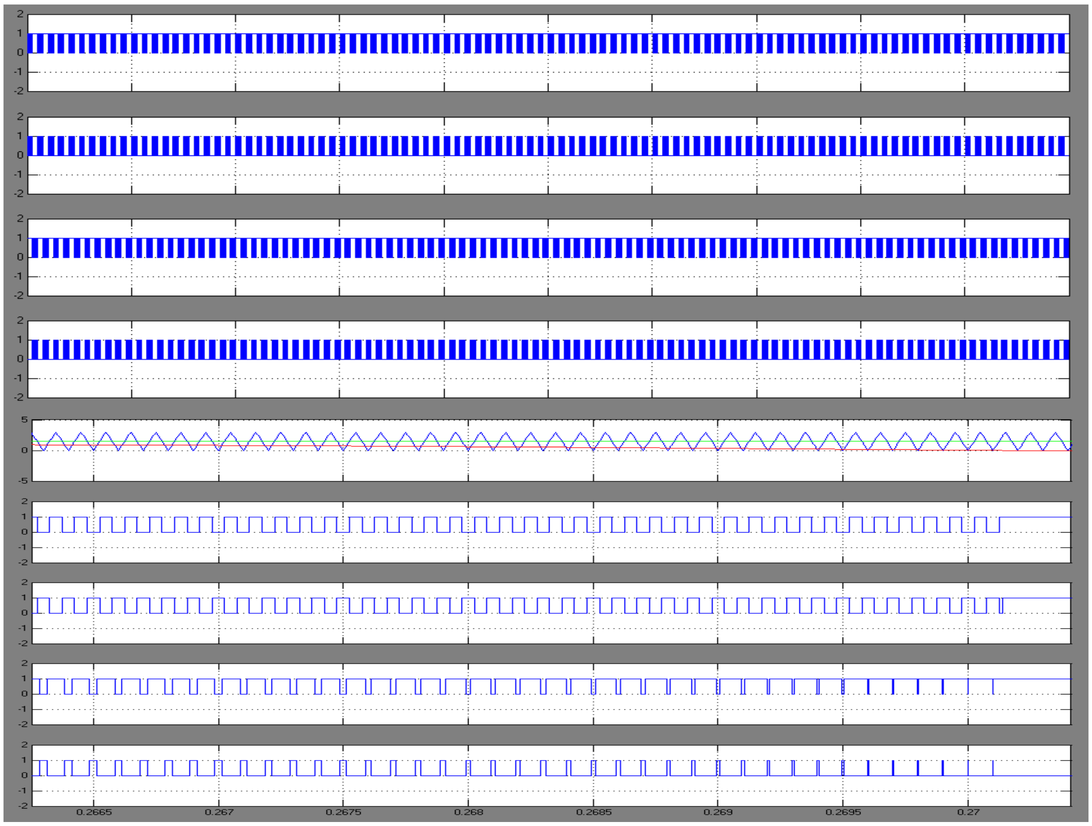


Fig.13. PWM pulses to the buck boost inverter switches

IV.CONCLUSIONS

The ABI has been proposed in this project. The topological derivation, the operating principle, and the modulation strategy have been presented. Active switches are utilized to perform voltage boost conversion without introducing additional passive elements; therefore, high power density and efficiency is achieved. The voltage boost ability of the ac–ac unit is similar to the transformer with flexible gain. The simulation verification is given to demonstrate the buck and boost operating modes and the developed modulation strategy of the ABI.

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