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Sparse AC Link Buck–Boost Inverter with Fabricated IGBT

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ABSTRACT

Power electronics dc-ac converters are widely used in electric power application. The soft-switching ac-link universal power converters can be configured as dc–dc, dc–ac, ac–dc, or ac–ac are compact, reliable and offer longer life when compared to other type of converter. However, they require more switches, which make the control process more complicated. This paper proposes a modified configuration for the dc–ac power conversion, which reduces the number of switches without changing the principles of operation. This converter is named as sparse ac-link buck–boost inverter. An important feature of this inverter is that it can be fabricated by IGBT modules. By using reverse blocking IGBTs in the sparse configuration, the efficiency of the proposed inverter will be improved significantly. This paper evaluates the performance of the proposed inverter through MATLAB simulation.

Keywords: Bidirectional, buck–boost converter, inverter, soft-switching.

1. INTRODUCTION

Soft-switching ac-link universal power converter, also called partial resonant ac-link converter, was first introduced. Being universal, the input and output of this convertermay be dc, ac, single-phase, or multiphase. Therefore, it can appear as dc–dc, dc–ac, ac–dc, or ac–ac configurations, the ac–ac and ac–dc configurations were studied in detail. The bidirectional and unidirectional three-phase inverter configurations for battery utility and photovoltaic applications were presented and thoroughly studied. The soft-switching ac-link universal power converter has several advantages over the other types of converters. This converter is an extension of the dc–dc buck–boost converter.

Therefore, unlike matrix converters and three-phase voltage source inverters, it is capable of both stepping up and stepping down the voltage. It can also change the frequency in a wide range. By adding the complementary switches and by modifying the switching scheme, the link inductor, which is the main energy storage element in this converter, can have alternating current instead of the direct current. This approach improves the performance of the converter and significantly increases the utilization of the link inductor. In this converter, the frequency of the link current and voltage is only limited by the characteristics of the switches and the sampling time of the microcontroller. Therefore, the frequency can be very high, which results in compact link and filter components.

By placing a small capacitor in parallel with the link inductor, the converter benefits from the soft switching. In this converter, unlike the resonant converters introduced in the link resonates just for a short time in each link cycle. Therefore, the LC pair has small reactive ratings; and there is low power dissipation in the link. The alternating link current and voltage of the soft-switching ac-link universal power converter, eliminates the need for the dc electrolytic capacitors at the link. The main problem with the electrolytic capacitor is its high-failure rate, especially at high temperatures.

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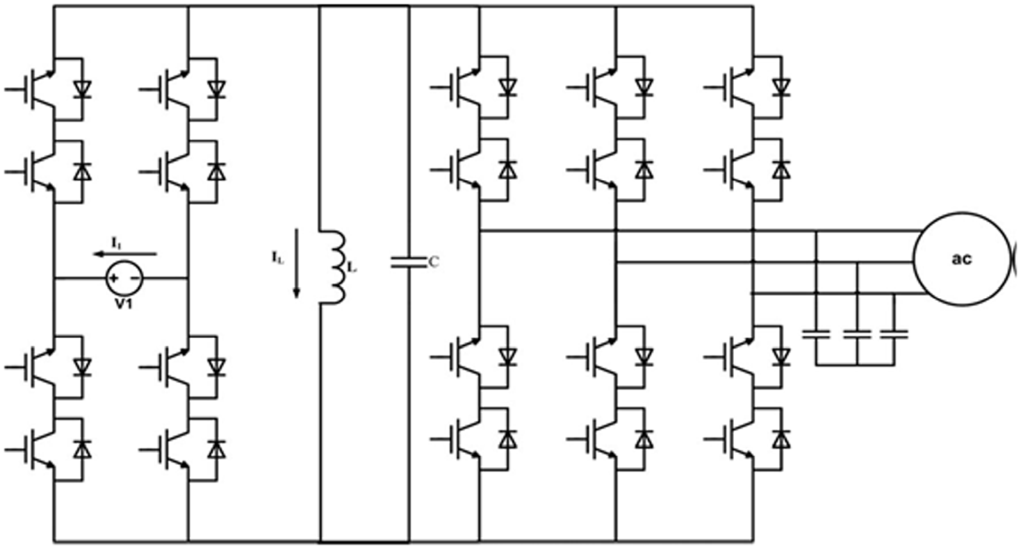

Figure 1: Ac link buck boost inverter

Therefore converters containing electrolytic capacitors are expected to have shorter lifetime. Another advantage of the ac link converters is the possibility of having galvanic isolation with a single-phase high-frequency transformer added to the link. In a three-phase voltage source inverter, galvanic isolation is provided by a bulky three-phase low-frequency transformer. Considering the aforementioned merits, the soft-switching ac link universal power converter is expected to be more compact and more reliable than conventional converters. Despite all the advantages of the ac-link buck–boost inverter, it requires more switches compared to the other inverters, which makes the control process more complicated.

In this paper, a modified configuration that has all the advantages of the ac-link buck–boost inverter but requires fewer switches is proposed. Despite reducing the number of switches, the principles of the operation in the proposed converter, which is named the sparse ac-link buck–boost Inverter, is the same as the original converter. This inverter offers higher reliability compared to the ac-link buck–boost inverter. Another important feature of the sparse configuration is that due to using unidirectional switches, it can be fabricated by switch modules. These modules are more compact and more cost-effective, compared to the discrete devices. Hence, the sparse configuration is expected to be less expensive, less complicated, and more compact compared to the ac-link buck–boost inverter. Despite using unidirectional switches, the sparse ac-link buck–boost inverter can support bidirectional flow of power. This method of switch reduction has not led to any switch count reduction at the dc side.

Therefore, we may keep the dc side as the original converter. There is a diode in series with each IGBT. Since conventional IGBTs cannot block the reverse voltage, a diode is connected in series with each IGBT. In case reverse-blocking IGBTs are used, the sparse configuration can be simplified further. The performance of the proposed configurations is similar to that of the ac-link buck–boost inverter. In this paper, a modified configuration that has all the advantages of the ac-link buck–boost inverter but requires fewer switches is proposed.

2. WORKING AND OPERATION

In the sparse configuration, the complementary switches are removed; however, the link current is still alternating. Fig. 1 represents this configuration, and as seen in this figure, the number of switches is reduced from 20 to 18. The input and output switch bridges contain unidirectional switches, and, in order to provide the link with alternating current, the intermediate cross-over switching circuits have been added to both the input side and the output side. Switches Si7, Si8, Si9, and Si10, which form the input-side intermediate cross-over switching circuit, and switches So7, So8, So9, and So10, which form the output-side intermediate

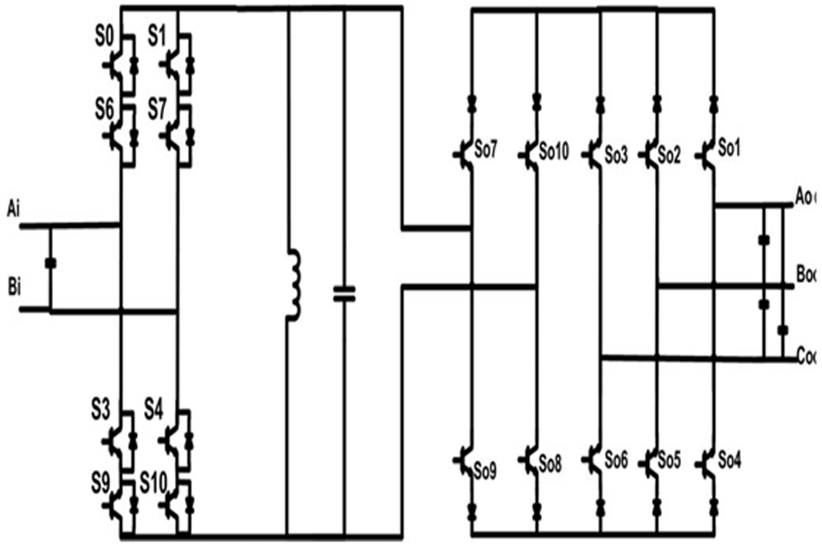

Figure 2: Sparse ac link buck boost inverter

cross-over switching circuit, permit the partially resonant circuit to operate bi directionally, which affords the advantages discussed earlier.

The performance of the proposed configurations is similar to that of the ac-link buck–boost inverter. The link current and voltage are exactly the same as that of the original configuration, and the partial resonance time is as short as in the original converter. As mentioned earlier the method used for reducing the number of switches does not lead to any switch count reduction at the dc side. In order to improve the efficiency, the dc side may be kept similar to the original configuration. There are three output phases and one charged link to be discharged into these phases. In order to have more control on the currents and minimized harmonics, the link discharging mode is split into two modes.

Although there are three phase-pairs in a three-phase system, considering the polarity of the current in each phase, only two of these phase-pairs can provide a path for the current when connected to the link. Again between each charging or discharging mode there is a resonating mode, which facilitates zero voltage turn ON of the switches and their soft turn OFF.

The basic operating modes of the sparse ac-link buck–boost inverter are represented in fig 3. Each link cycle is divided into 12 modes, with 6 power transfer modes and 6 partial resonant modes taking place alternately. The link is energized through the input phase pairs during modes 1 and 7 and is de energized to the output phase pairs during modes 3, 5, 9, and 11. Modes 2, 4, 6, 8, 10, and 12 are resonating modes during which no power is transferred and the link resonates. Before the start of mode 1, the incoming switches, which are supposed to conduct during mode 1, are turned ON (S3 and S8 in Figs. 3);

However they do not conduct immediately, because they are reverse-biased. Once the link voltage, which is resonating before mode 1, becomes equal to the voltage across the dc side, proper switches (S3 and S8) are forward biased initiating mode 1. This implies that the turn ON of the switches occurs at zero voltage as the switches transition from reverse to forward bias. Therefore, the link is connected to the dc source via switches which charge it in the positive direction. The link charges until the dc-side current averaged over a cycle time, meets its reference value. Input-side switches are then turned OFF.

During mode 2 none of the switches conduct. The link resonates and the link voltage decreases until it reaches zero. At this point, the incoming switches that are supposed to conduct during modes 5 and 7, are turned ON (S13, S14, and S18 in Figs 3); however being reverse-biased they do not conduct immediately. Once the link voltage reaches VACO (assuming |VACO| is lower than |VABO|) switches S14 and S18 become forward biased and they start to conduct initiating mode 3.

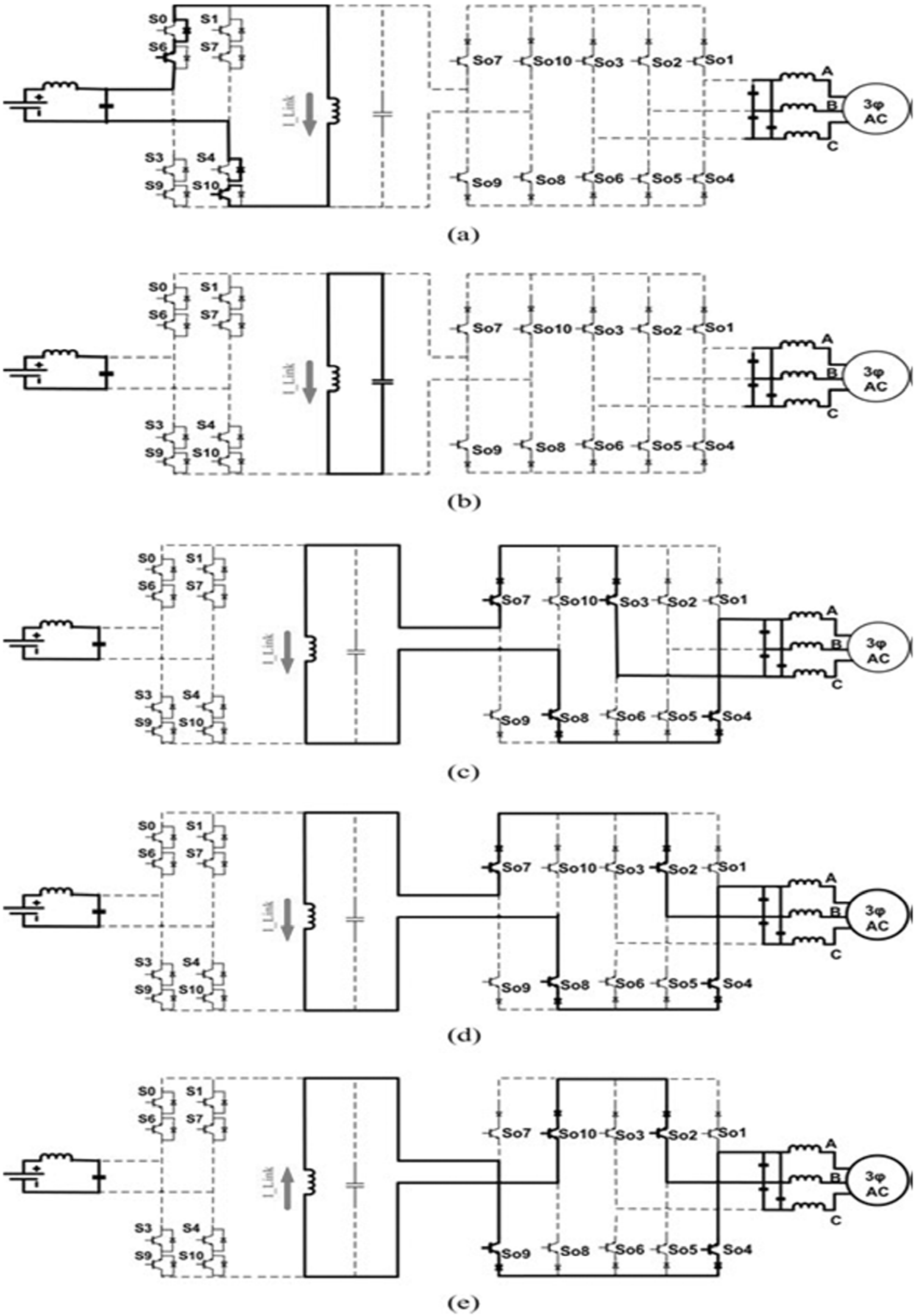

Figure 3: Behavior of the sparse ac-link buck–boost inverter during different modes of operation: (a) Mode1. (b)Mode2. Mode4 and Mode 6.(c) Mode 3. (d) Mode 5. (e) Mode 11.

During mode 3, the link is discharged into the chosen phase pair until the current of phase C at the output-side averaged over a cycle meets its reference. At this point S14 will be turned OFF initiating another resonating mode.

During mode 4, the link is allowed to swing to the voltage of the other output phase pair chosen during Mode 2. For the case shown in Figs.2, it swings from *V*CAO to *V*BAO. Once the link voltage becomes equal to the voltage across the output phase pair AB, switches S13 and S18 become forward-biased, initiating mode 5.

During mode 5, the link discharges to the selected output phase pair until there is just sufficient energy remained in the link to swing to a predetermined voltage (Vmax), which is slightly higher than the maximum input and output line-to-line voltages.

At the end of mode 5, all the switches are turned OFF allowing the link to resonate during mode 6. Modes 7 through 12 are similar to modes 1 through 6, except that the link charges and discharges in the reverse direction. For this, the complimentary switch on each leg is switched when compared to the ones switched during modes 1 through 6. For the ac–dc mode of operation, the link is charged from the output phase pairs during modes 1 and 3, and then it is discharged into the dc side during mode 5.

The current/voltage waveforms at different modes are the same as those of the ac-link buck–boost inverter. Modes 1–6 in the modified configuration are similar to those of the original converter, except other than turning on the proper switches on the output switch bridges; So7 and So8, on the output intermediate cross-over switching circuit, should be turned ON during modes 3–5. Although the output switch bridge contains unidirectional switches, So7–So10 (referenced above as intermediate cross-over switching circuit) Enable the link to conduct both positive and negative currents.

Therefore, during modes 7–12, the same output switches as modes 1–6 will be conducting; however, instead of So7 and So8, switches So9 and So10 conduct during modes 9–12. By adding a single-phase, high-frequency transformer to the link, the sparse ac-link buck–boost inverter can provide galvanic isolation. In practice, due to leakage inductance of the transformer, the link capacitor needs to be split into two capacitors placed at the primary and the secondary of the transformer. Otherwise at the end of the charging or discharging mode, depending on which side the capacitor is located at, the current of the leakage inductance will have an instantaneous change, which results in voltage spike.

3. MODULATION STRATEGIES

In the sparse configuration, the complementary switches are removed. Important feature of the sparse configuration is that due to using unidirectional switches, it can be fabricated by switch modules.

These modules are more compact and more cost-effective, compared to the discrete devices. Hence, the sparse configuration is expected to be less expensive, less complicated, and more compact compared to the ac-link buck–boost inverter.

Despite using unidirectional switches, the sparse ac-link buck–boost inverter can support bidirectional flow of power.

As mentioned earlier the method used for reducing the number of switches does not lead to any switch count reduction at the dc side. In order to improve the efficiency, the dc side may be kept similar to the original configuration.

4. FEATURES OF SPARSE

✓ It requires lower switches.

✓ Control process is easy and efficiency can be increased.

- ✓ No need for dc link capacitor, modules are more compact and cost effective.
- ✓ Low failure rate by using reverse blocking IGBT.
- ✓ Average current of the switches in the sparse configuration is higher than the average current of the switches in the original configuration.
- ✓ Switches have longer lifetime failure rate also low and efficiency also increased.
- ✓ The alternating link current and voltage of the soft switching ac link universal power converter, eliminates the need for the dc electrolytic capacitor at the link.

5. SIMULATION RESULTS

In this section, the performance of the bidirectional sparse ac link buck–boost inverter will be evaluated through simulations.

Output for load current

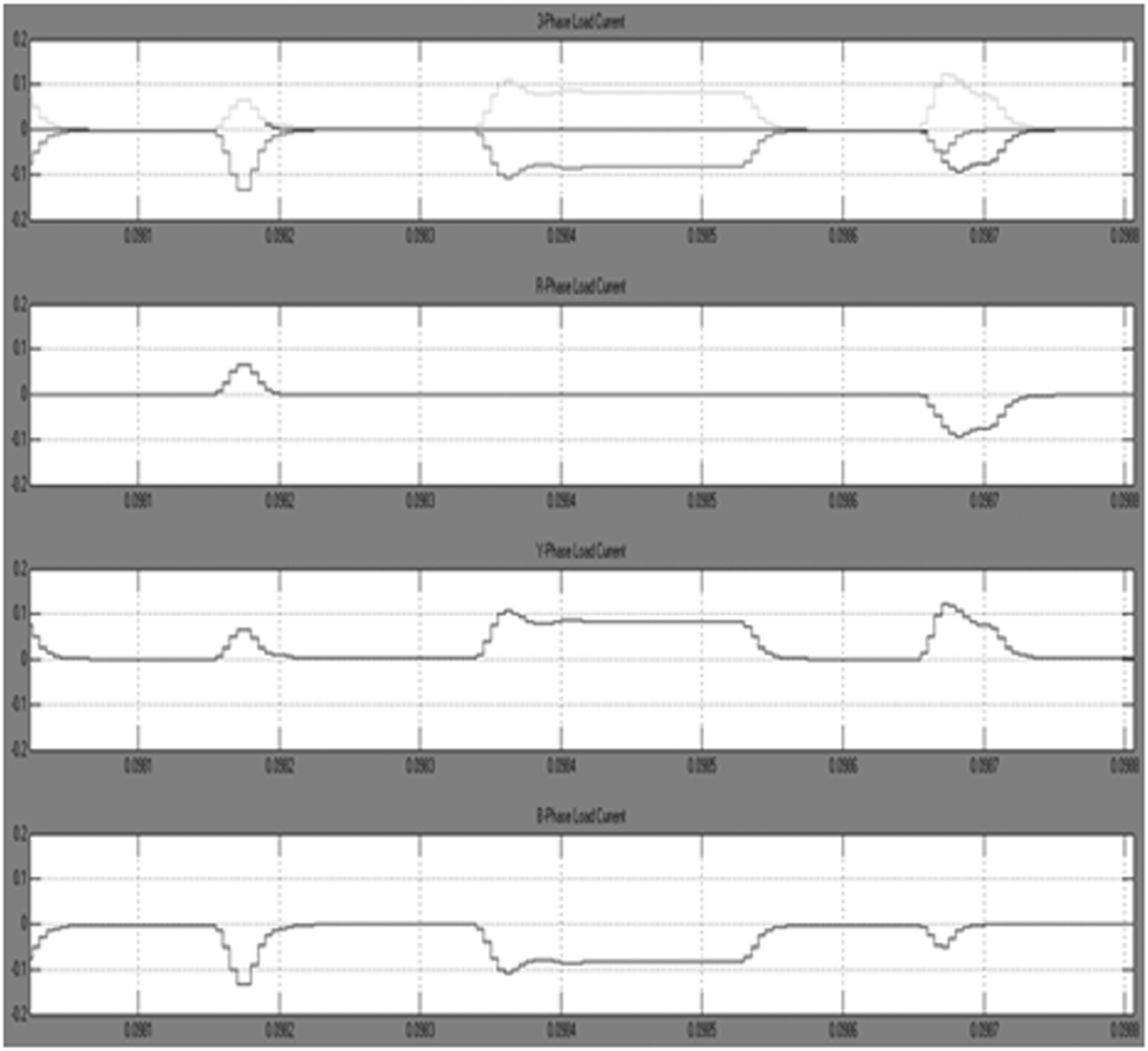

Figure 4: Output for load current

Output load voltage

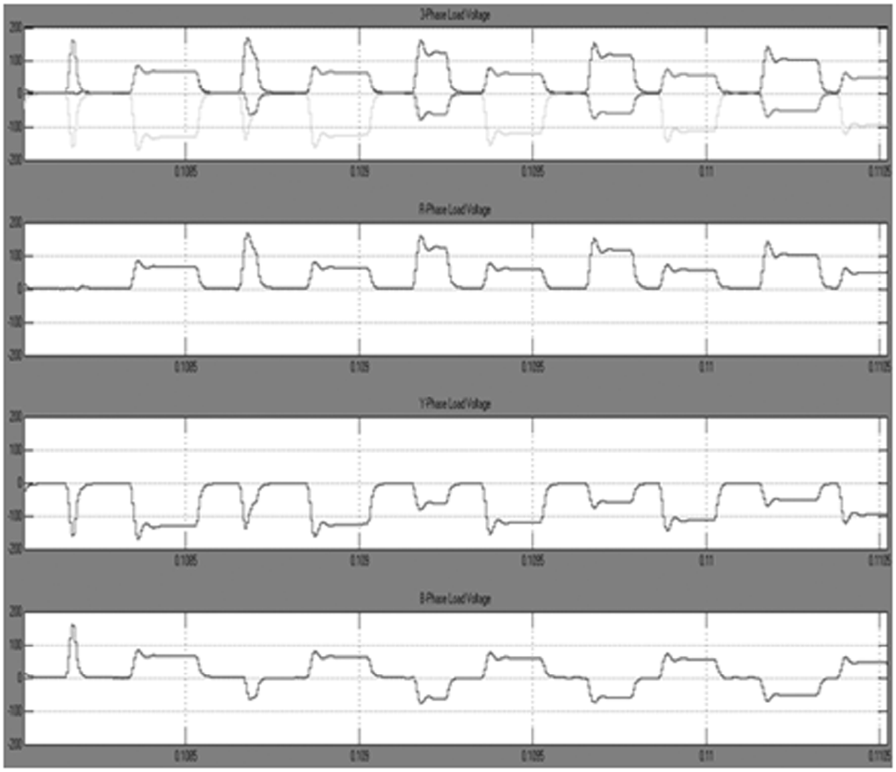

Figure 5: output load voltage

Output for inverter gate pulse

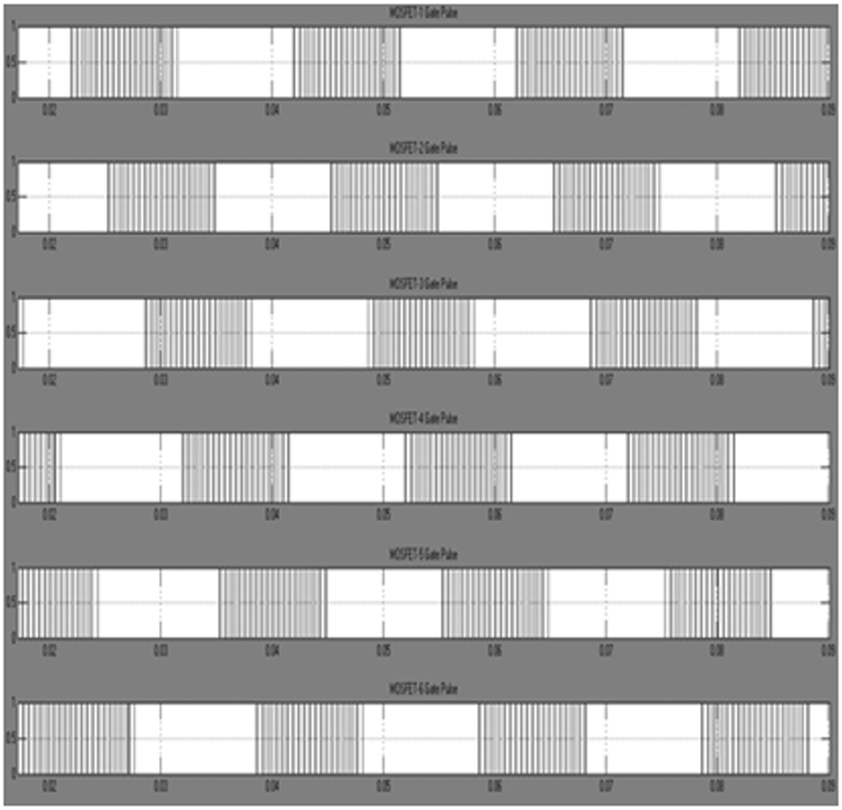

Figure 6: Output for inverter gate pulse

Output for rectifier voltage and current

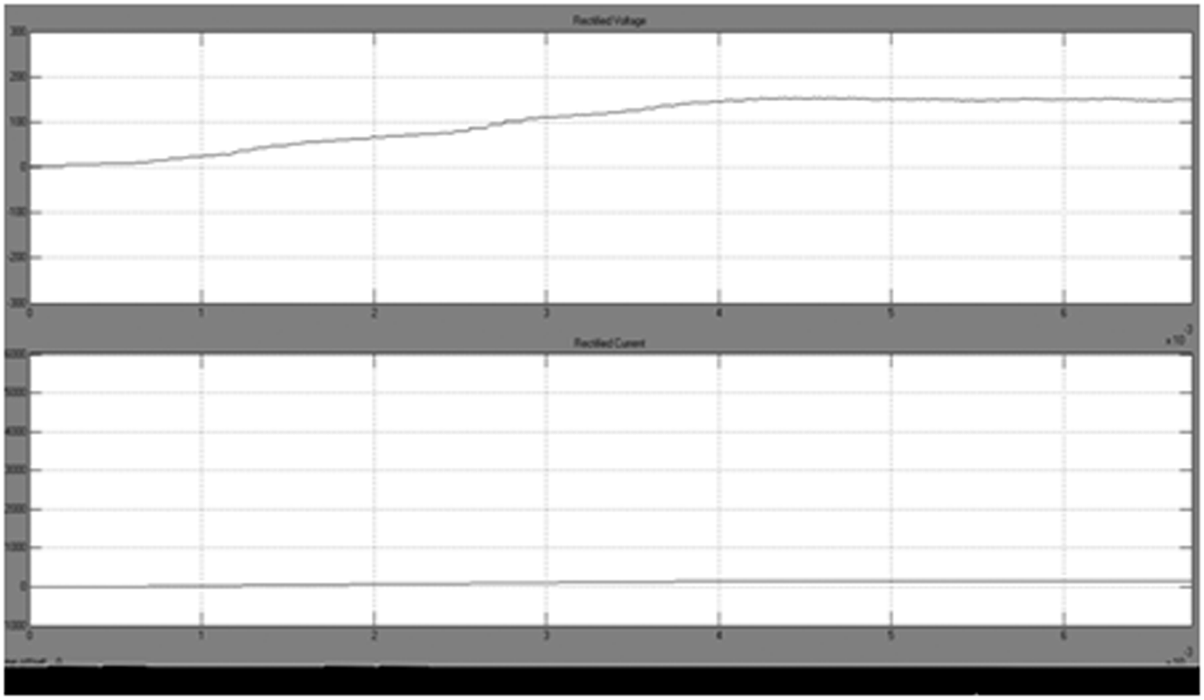

Figure 7: Output for rectifier voltage and current

Output for inverter MOSFET gate pulse

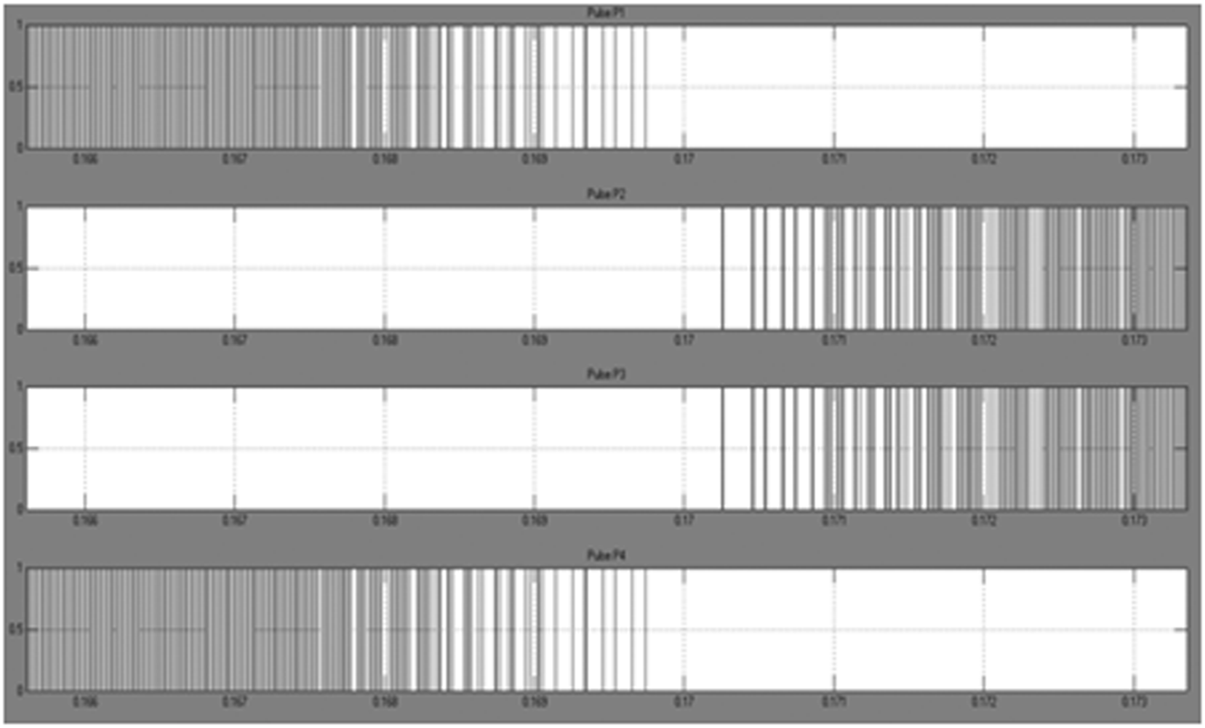

Figure 8: Output for inverter MOSFET gate pulse

6. APPLICATIONS

- The bidirectional and unidirectional three phase inverter configurations for battery utility and photovoltaic applications were presented.

- Sparse AC-Link Buck-Boost Converter may be utilized in a wide variety of applications ranging from low and medium voltage motor drives, to transformer-less solar inverters, large wind power converters, many other applications that may benefit from its conversion versatility.

7. CONCLUSION

In this paper, the switch current rating, the efficiency, and the failure rates of the proposed inverter were compared with those of the original configuration. It was shown that the switches in the proposed configuration should withstand higher average current; however, the peak current they tolerate is the same as the peak current switches in the ac-link buck–boost inverter tolerate. Therefore, the proposed configuration does not necessarily lead to high current switches. The proposed inverter has all the advantages of the ac-link buck–boost inverter, including zero voltage turn on and soft turn-off of the switches, alternating link current, and the possibility of having galvanic isolation with the addition of a single-phase high-frequency transformer. The efficiency of the 1.5 kW sparse ac link buck boost inverter is about 2% lower than that of the ac link buck boost inverter. By using reverse-blocking IGBTs its efficiency will be increased 4%. It was also shown that the failure rates of the 1.5 kW sparse ac link buck boost inverter are about 12% lower than that of the original configuration.

8. REFERENCES

[1] W. C. Alexander, "Universal power converter," U.S. Patent 2008/ 0013351A1, Jan. 17, 2008.

[2] A. Balakrishnan, H. A. Toliyat, and W. C. Alexander, "Soft switched ac link buck boost converter," in *Proc. Twenty-Third Ann. IEEE Appl. Power Electron. Conf. Expo.*, Feb. 2008, pp. 1334–1339.

[3] H. A. Toliyat, A. Balakrishnan, M. Amirabadi, and W. Alexander, "Soft switched ac-linkAC/AC andAC/DC buck-boost converter," in *Proc. IEEE Power Electron. Spec. Conf.*, 2008, pp. 4168–4176.

[4] M. Amirabadi, H. A. Toliyat, andW.Alexander, "Battery-utility interface using soft switched AC link supporting low voltage ride through," in *Proc. IEEE Energy Convers. Congr. Expo. Conf.*, 2009, pp. 2606–2613.

[5] M. Amirabadi, A. Balakrishnan, H. Toliyat, and W. Alexander, "High frequency ac-link PV inverter," *IEEE Trans. Ind. Electron.*, vol. 61, no. 1, pp. 281–291, Jan. 2014.

[6] M.Amirabadi, "Soft-switching high-frequency ac-link universal power converters with galvanic isolation," Ph.D. dissertation, Texas A&M University, College Station, TX, USA, 2013.

[7] T. A. Lipo, "Resonant link converters: A new direction in solid state power conversion," presented at Second Int. Conf. Electrical Drives, Eforie Nord, Romania, Sep. 1988.

[8] P. K. Sood, T. A. Lipo, and I. G. Hansen, "A versatile power converter for high frequency link systems," *IEEE Trans. Power Electron.*, vol. 3, no. 4, pp. 383–390, Oct. 1988.

[9] F. C. Schwarz, "An improved method of resonant current pulse modulation for power converters," *IEEE Trans. Ind. Electron. Control Instrum.*, vol. 23, no. 2, pp. 133–141, May 1976.

[10] Y. Murai and T. A. Lipo, "High-frequency series-resonant DC link power conversion," *IEEE Trans. Ind. Appl.*, vol. 28, no. 6, pp. 1277–1285, Nov./Dec. 1992.

[11] D. M. Divan, "The resonant DC link coverter—A new concept in static power conversion," in *Proc. IEEE IAS Annu Meet.*, pp. 648–656.