Soft-Switching Series AC-Link Inverter by Zero-Current Switching.

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Abstract- This paper proposes a novel bidirectional inverter, named series ac-link inverter. This three-phase inverter belongs to a new class of partial resonant ac-link converters in which the link is formed by a series ac inductor/capacitor (LC) pair having low reactive ratings. The input and output of this converter can be either dc, ac, single-phase, or multiphase. Therefore, they can appear as dc–dc, dc–ac, ac–dc, and ac–ac configurations. In all of these configurations, the ac capacitor is the main energy-storage element, and the inductor is merely added to facilitate the zero-current turnoff of the switches and their soft turn-on. Due to the zero-current turnoff of the switches in the proposed converter, the use of SCRs with natural commutation is possible as well. Since the current and voltage of the link are both alternating, no bulky dc-electrolytic capacitors are required in this converter. This paper mainly focuses on bidirectional dc to three-phase ac conversion. This single-stage inverter can step up or step down the voltage in a wide range. If galvanic isolation is required a single-phase high-frequency transformer can be added to the link. In the proposed inverter, the power can flow in both directions, and therefore, it is an excellent candidate for battery-utility interface and electric vehicle applications. In this paper, the principles of the operation of the proposed inverter, along with its design and analysis, are studied. Moreover, the performance of the proposed configuration is evaluated in this paper. Both simulation and experimental results are included

Keywords- Bidirectional power flow, dc–ac power convert-ers, galvanic isolation, high-frequency ac link, inverters, partial resonant converters, soft switching, universal converters, zero-current switching.

I. INTRODUCTION

most of these renewable energy sources are intermittent in nature. Therefore, an energy storage is needed in renewable en-ergy systems to store the energy and return it back when needed. Small battery energy-storage systems (BESSs) were very pop-ular until the emergence of the ac systems, which limited their widespread use. Recently, due to the existence of the loads that are intolerant of power-line anomalies and also the presence of the intermittent renewable energy sources, BESSs have be-come popular again [1]. Clearly, a power converter is needed to connect an energy storage to the grid. This converter should be capable of control-ling the current or voltage at both sides. There are two common solutions for interfacing an energy storage and the grid. The first solution is using two individual power converters: an inverter and a rectifier operating independently. A more reliable and compact solution is using a bidirectional inverter. A common configuration is shown in Fig. 1. The main problem associated with this converter is the existence of the dc link, which requires electrolytic capacitors. The electrolytic capacitors are very sen-sitive to temperature and may cause severe reliability problems, particularly at high temperatures [2]. Therefore, power convert-ers which have dc-electrolytic capacitors are expected to have higher failure rates at higher temperatures. In [3], a bidirectional soft-switching high-frequency ac-link inverter was introduced. This inverter, shown in Fig. 2, is an ex-tension of the dc–dc buck–boost converter; therefore, it is capa-ble of both stepping up and stepping down the voltage. Several modifications have been applied to the buck–boost converter to provide the alternating link current and the soft switching of the switches. The switches are all turned on at zero voltage, and their turnoff is soft.

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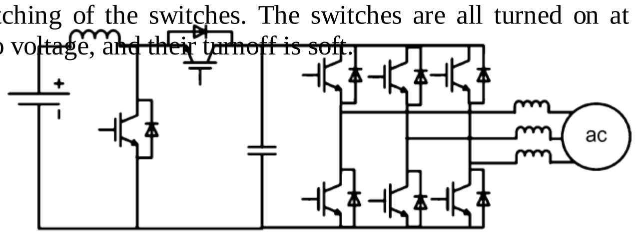
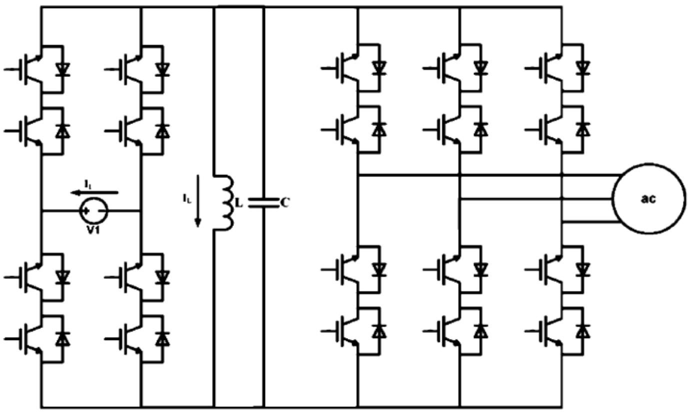
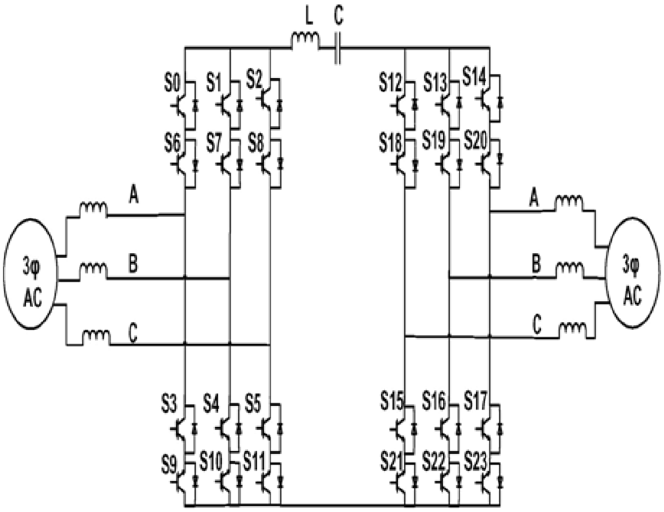


Conventional bidirectional inverter.



Bidirectional parallel ac-link inverter introduced in [3] and [4].

CIRCUIT DIAGRAM:

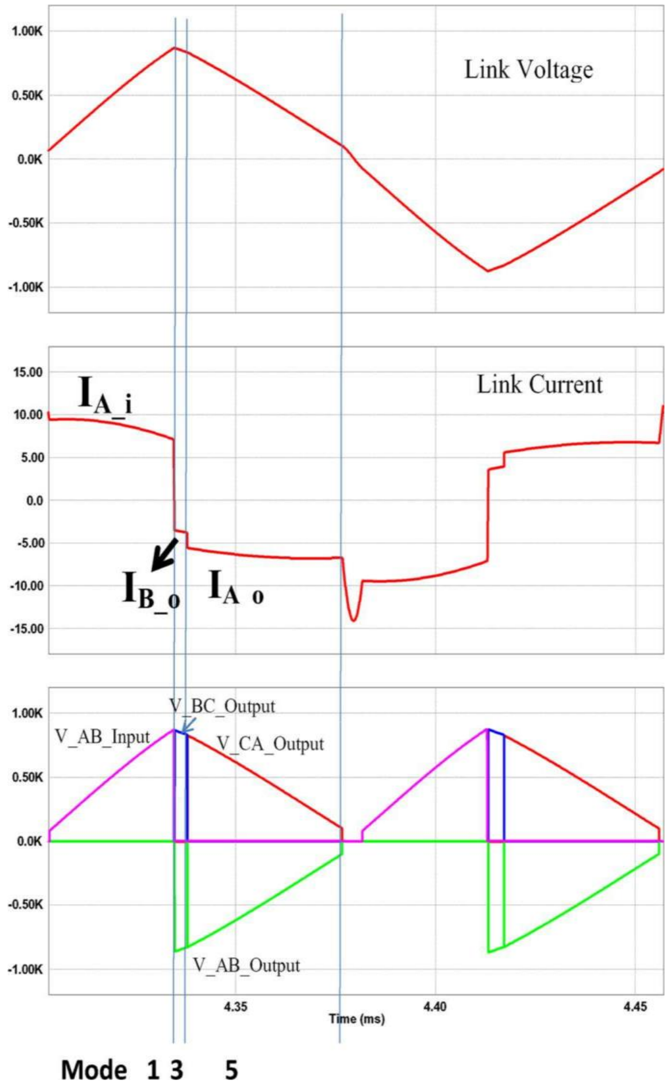


This paper proposes another type of bidirectional soft-switching high-frequency ac-link inverter, which is a dual of the inverter introduced in [3]. This inverter, named series ac-link inverter, belongs to a new class of power converters named series partial resonant converter (SEPARC) or series ac-link universal power converter. The applications of this converter in PV and wind power generation have been studied in [8] and [9]. In the series ac-link inverter, shown in Fig. 3, an ac capacitor is the main energy-storage component, and an inductor is added in series with the link capacitor to facilitate the zero-current turnoff and the soft turn-on of the switches. Similar to the parallel ac-link inverter, switching losses are negligible in this converter, and devices are subject to minimum current and voltage stress. Therefore, no snubber circuit is needed in the SEPARC. In this converter, the link current and link voltage are both alternating, and their frequency can be very high. This results in the elimination of the dc capacitors and the low-frequency transformers. Since the switches are turned off at zero current in this converter, it is expected that SCRs with natural commutation be usable instead of the MOSFETs or insulated-gate bipolar transistors (IGBTs). SCRs have several advantages over the other types of switches. They have low losses, are available at both high current and high voltage ratings, and are inexpensive and reliable. These characteristics make them an excellent candidate for high-power applications and reliability-demanding applications. As mentioned earlier, the SEPARC is a universal converter. Therefore, its input and output each can be dc, ac, single-phase, or multiphase.

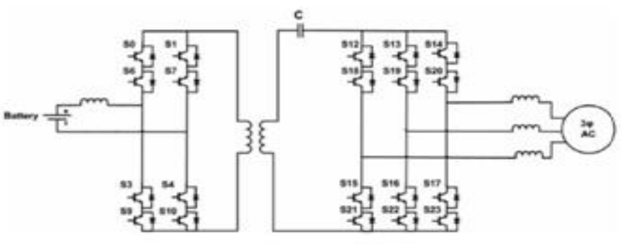
PRINCIPLES OF OPERATION:

As mentioned earlier, the proposed inverter, shown in Fig. 3, is an extension of the dc–dc Cuk converter. Therefore, in case of the dc–ac conversion, the link capacitor will be charged through the dc side and then discharged into the ac side. However, there are three phases at the ac side and just one link to be discharged. In order to have lower total harmonic distortions (THDs), the discharging mode will be split into two modes so that all three phases are involved. During the second half cycle of the link, the link capacitor will be charged from the input and then discharged into the output phases again; however, this time, the link capacitor is charged and discharged in a reverse direction. This is feasible due to the existence of the bidirectional switches and leads to an alternating link voltage and, consequently, the elimination of the dc capacitor. In this converter, there is a resonating mode between each power transfer mode (charging or discharging modes). The proposed switching scheme is developed such that these resonating modes result in the zero-current turnoff of the switches and their soft turn-on

In a three-phase ac-to-dc conversion, the link capacitor is charged through the ac side and then discharged into the dc side. Therefore, in this case, the charging mode is split into two modes. Similar to the dc–ac conversion, the link will be charged and discharged in both positive and negative directions, and a resonating mode occurs between each power transfer mode. In both dc-to-three-phase-ac and three-phase-ac-to-dc conversion, the link cycle is divided into 12 modes, including 6 power transfer modes and 6 resonating modes.



PROPOSED INVERTER WITH GALVANIC ISOLATION:



The series ac-link inverter can provide galvanic isolation by adding a single-phase high-frequency transformer to the link. In this case, the leakage inductance of the transformer may play the role of the link inductance. The schematic of the inverter with galvanic isolation .

Modes 7–12 are similar to modes 1–6 except that the polarity of the link voltage/current is reversed.

The principles of the operation can be easily extended to ac-to-dc conversion. The only difference is that, in this case, modes 1 and 3 are charging modes, during which the ac-side currents charge the link, and mode 5 is a discharging mode during which the link is discharged into the dc side. Fig. 8 shows the waveforms corresponding to the ac–dc conversion.

To simplify the switching scheme, first, the switches conducting in each power transferring mode (modes 1, 3, 5, 7, 9, and 11) need to be determined, and the switches conducting during the resonating mode are determined such that they result in the zero-current turnoff and soft turn-on of the switches as well as the minimum number of switching in each cycle.

The switches that conduct in each power transfer mode can be simply determined according to the polarity of the link current and voltage. For example, for the dc-to-ac conversion system, during mode 1, the link voltage and current are both positive. The unfiltered input voltage is positive, and the input current is in the same direction as the link current; therefore, switches S6 and S10 conduct. For the three-phase system, this will be more complicated, as there are three phase pairs. The phase pair that has the maximum line-to-line reference voltage is supposed to be involved during two modes. The polarity of the line-to-line reference voltages, along with the polarities of the link current and voltage, determines the main switches that will be conducting during modes 3 and 5. The phase that is not involved in forming the maximum line-to-line voltage (Phase C_o in Fig. 6 and phase A_o in Fig. 8) helps with the transition

II. DESIGN AND ANALYSIS:

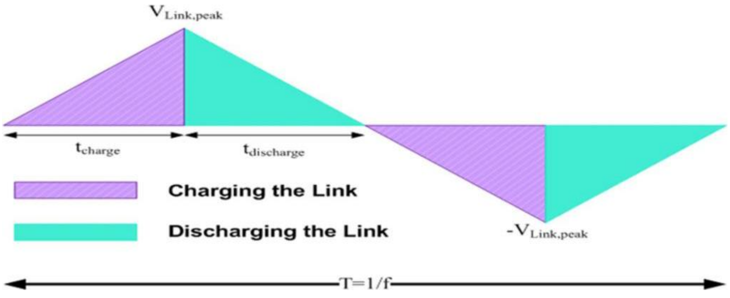
To simplify the design procedure, the resonating time which is much shorter than the power transfer time will be neglected. Moreover, for the dc-to-three-phase-ac conversion, the discharging is assumed to take place in one equivalent mode instead of two modes during each power cycle. For this operation, the link is assumed to be charged through the dc source and then discharged into a virtual load with output equivalent current. Considering the principles of the operation, it can be shown that the output equivalent voltage, which is the voltage across the virtual load, is

$$V_{o,eq} = \frac{3\sqrt{3}}{\pi} \times V_{o,peak} \qquad (1)$$

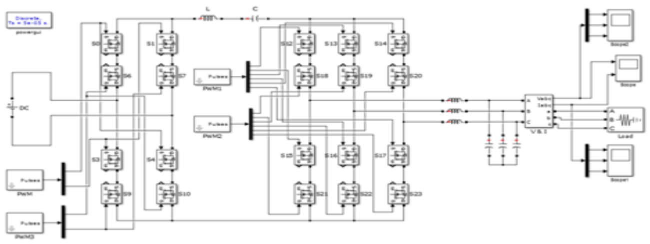
where $V_{o,\text{peak}}$ is the peak of the filtered ac-side voltage. The output equivalent current can then be calculated as

$$I_{o,eq} = \frac{\pi}{2\sqrt{3}} \times I_{o,\text{peak}} \times \cos\theta_o \qquad (2)$$

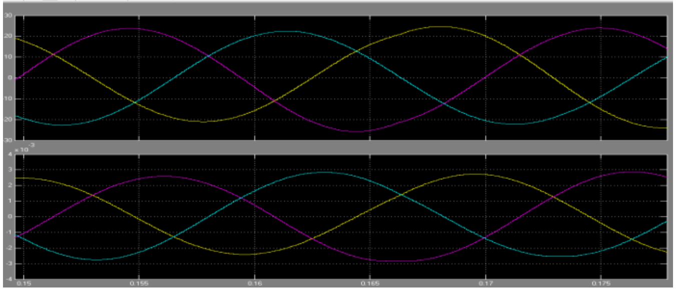
during the charging mode (mode 1), the dc-side current charges the link capacitor, and the voltage across this capacitor increases linearly. During the equivalent de-energizing mode (modes 3 and 5), the charged link capacitor is discharged into the virtual load. Fig. 10 shows one cycle of the link voltage when simplified for the design procedure. The following equations describe the behavior of the circuit during the charging and discharging modes, respectively In the aforementioned equations, I_{dc}, $V_{\text{Link,peak}}$, t_{charge}, and $t_{\text{discharge}}$ represent the average of the dc-side current, peak of the link capacitor voltage, total energizing time during.



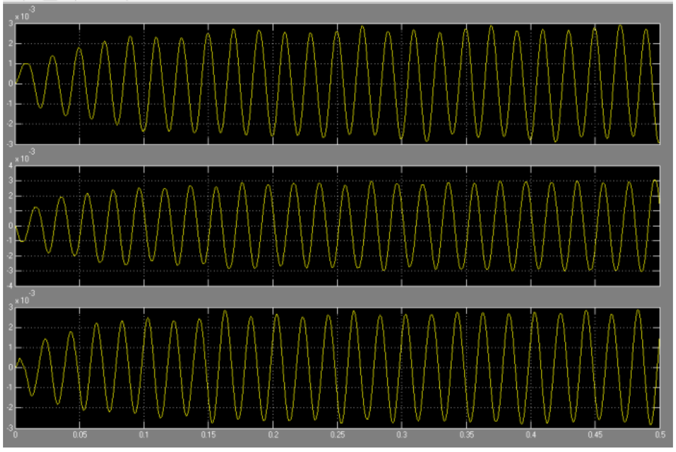
SIMULATION RESULTS:



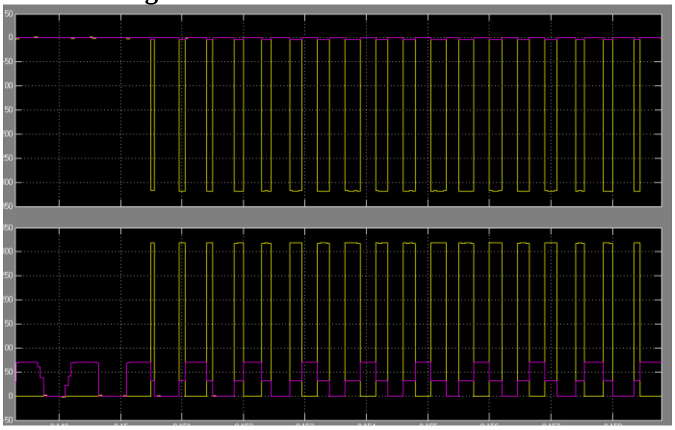
Voltage and current:



Voltage measurement:



Mosfet voltage and current:



III. CONCLUSION

This paper introduced a bidirectional soft-switching ac-link inverter. This inverter belongs to a new class of power convert-ers called SEPARCs or series ac-link universal power convert-ers. Being universal, this converter may be configured as dc–dc, dc–ac, ac–dc, or ac–ac. In this paper, the bidirectional dc-to-three-phase-ac conversion was studied. In the proposed inverter, the link current and voltage are both alternating. Therefore, no dc-electrolytic capacitor or low-frequency transformers are used in this inverter. Galvanic isolation can be provided by adding a single-phase high-frequency transformer to the link.

In this converter, all the switches have a soft turn-on, and they are turned off at zero current. Therefore, it is expected that SCRs with natural commutation are usable in this converter. This paper studied the principles of operation in both dc-to-three-phase-ac and three-phase-ac-to-dc conversion modes. The design and analysis of this inverter were also studied in this paper, and the converter was evaluated through simulation and experimental results.

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