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# A Soft Switched Isolated Bidirectional DC-DC Converter

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**ABSTRACT**: A soft switched bidirectional DC-DC converter which is isolated is introduced here. The soft switching is designed by using resonant converter techniques. The conventional bidirectional converters works with hard switching, which results in additional power loss. By providing soft switching techniques the power loss can be well reduced. This converter consists of a high frequency transformer, which acts as an interface between a high-voltage dc bus line and a low voltage DC bus line. During the step down stage, it converts 200 V to 24 V, and during step up stage, the reverse action takes place. The DC blocking capacitor in the high-voltage side is used to reduce the voltage on the transformer. Two auxiliary switches and a resonant circuit contribute to reduced switching loss as compared to conventional converters. The proposed bidirectional converter has been analyzed, and theoretical analysis has been verified by simulation by using PSIM software. The converter features high voltage gain and current reduced stress in converter primary switches.

**KEYWORDS:** Bidirectional Converter, PSIM, Soft Switching, ZVS.

## I. INTRODUCTION

Bidirectional DC-DC converters allow transfer of power between two dc sources, in either direction. Due to their ability to reverse the direction of flow of current, and thereby power, while maintaining the voltage polarity at either end unchanged, they are beneficial when use in applications like dc uninterruptable power supplies, battery charger circuits, telecom power supplies and computer power systems. Generally, the voltage difference between the battery and DC bus is large. So bidirectional DC-DC converter with steep voltage conversion ratio is required for the above applications. Theoretically, high voltage conversion ratio can be achieved by power converter in very high or very low duty ratio. But, the efficiency of power converter is reduced at very large or very small duty ratio due to the effect of parasitic elements. For the different applications, bidirectional DC-DC converters may be isolated type or non-isolated type. High voltage conversion ratio in bidirectional dc-dc converters is able to be achieved easily by adjusting turns ratio of the isolated transformer.

Compared with high step up and high step down converters, bidirectional high conversion ratio converters can significantly reduce the overall system volume, cost, and number of components. The non isolated bidirectional converters can be constructed by using coupled inductors, switched capacitor techniques, and cascade techniques, to obtain a high conversion ratio with an appropriate duty ratio. However, non isolated converters fail to meet the safety standards of galvanic isolation in many applications. Bidirectional isolated DC–DC converters derived from push–pull topologies, full-bridge topologies and series resonant full-bridge converters can increase the conversion ratio by adjusting the turns ratio of the transformer. However, a high turns ratio increases the transformer size. It is able to conclude that an isolated bidirectional converter which works in hard switching condition can be converted in to soft switched one by introducing additional resonant circuit. The resonant circuit may be either with auxiliary switch or with conventional LLC resonant circuit. Here an isolated bidirectional DC-DC converter with soft switching is proposed by the introduction of auxiliary switches and a resonant tank circuit.

The proposed converter provides the desired bidirectional flow of power for battery charging and discharging using only one transformer in a single converter, as opposed to two independent isolated power converters in conventional schemes. In the case of conventional bidirectional DC-DC converter, the main switches operate under hard switching condition in boost mode and buck mode. Since this switching loss is one of serious loss, it will result in drop of the

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system efficiency. General method to improve the efficiency is to use only auxiliary switches which help the ZVS operation. In order to deal with the hard switching problem, not only auxiliary switches but also auxiliary resonant circuit is employed. That is, two auxiliary switches, resonant capacitors and resonant inductor help the main and auxiliary switches working under ZVS condition.

## II.CONFIGURATION OF OF BIDIRECTIONAL CONVERTERS

The Bidirectional DC-DC converters serves the purpose of stepping up or stepping down the voltage level between its input and output along with the capability of power flow in both the directions. Bidirectional DC-DC converters have attracted a great deal of applications in the area of energy storage systems for Hybrid Vehicles, Renewable energy storage systems, uninterruptable power supplies and fuel cell storage systems. Traditionally they were used for the motor drives for the speed control and regenerative braking. The bidirectional DC-DC converters are employed when the dc bus voltage regulation has to be obtained along with the power flow capability in both the direction [1]. One such example is the power generation by wind or solar power systems, where there is a large fluctuation in the generated power because of the large variation and uncertainty of the energy supply to the conversion unit (wind turbines and PV panels) by the primary source. These systems cannot act as a standalone system for power supply because of these large fluctuations and therefore these systems are always backed up and supported by the auxiliary sources which are rechargeable such as battery units or super capacitors. These sources supplement the main system at the time of energy deficit to provide the power at regulated level and get recharged through main system at the time of surplus power generation or at their lower threshold level of discharge. Therefore a bidirectional DC-DC converter is needed to allow power flow in both directions at the regulated level. Principle of the switched-diode-capacitor cell is that: when the main switch $S_1$ is turned on, diodes $D_1$, $D_2$ are turned off with capacitors $C_1$, $C_2$ discharged in series and the inductor charged in parallel, when S is turned off, diodes $D_1$, $D_2$ are turned on with $C_1$, $C_2$ charged in parallel and the inductor discharge serially. A high voltage gain can be attained since two capacitors are discharged in series and charged in parallel and inductor charged in parallel and discharged serially automatically by the on-off transition of the main switch.

These converters can regulate a wide range of power from few watts to hundreds of kilowatts. Galvanic isolation is required in certain applications demanding Personnel safety, noise reduction as well as proper operation of protection systems. Also certain systems require voltage matching between the different stages for the proper design and the optimization of different stages. Generally Voltage matching and galvanic isolation is achieved by the transformer in a power electronic circuitry. This necessitates the requirement of the AC link for the energy transfer [3]. Thus the system complexity grows up with the incorporation of all this features. This system requires two switching DC to AC converters operating at a high frequency so as to convert the DC input to high frequency ac quantities. Galvanic isolation between the source and load side is provided by the high-frequency transformer. Transformer also performs voltage matching between the source and the load side since the voltage ratio between them is very high. Isolated bidirectional DC-DC converters can be broadly classified into two categories on the basis of their configuration:

1) A current fed isolated bidirectional DC-DC converter has an inductor at its terminals which acts like a current source like a conventional boost converter with an inductor at the input terminals.
2) A voltage fed isolated bidirectional DC-DC converter has a capacitor at its terminals which acts like a voltage source like a conventional buck converter with a capacitor at its input terminals.

Basically, bidirectional DC-DC converters can be classified into two categories depending on the Galvanic isolation between the input and output side.

1. Non-Isolated Bidirectional DC-DC converters
2. Isolated Bidirectional DC-DC converters

Basically a non-isolated bidirectional DC-DC converter can be derived from the unidirectional DC-DC converters by enhancing the unidirectional conduction capability of the conventional converters by the bidirectional conducting switches [2]. Due to the presence of the diode in the basic buck and boost converter circuits, they do not have the inherent property of the bidirectional power flow. This limitation in the conventional Boost and Buck converter circuits

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can be overcome by introducing a power MOSFET or an IGBT having an anti parallel diode across them to form a bidirectional switch and hence allowing current conduction in both directions for bidirectional power flow.

If the converter circuit does not have any auxiliary components, then the switches operates under hard switching operation and this leads to the considerable amount of the power loss and high electrical stress within the switches during turn on and turn off condition because of very large values of the current and voltage simultaneously across it. Generally in all the converters operating under hard switching conditions and particularly in the high power converters, switching losses puts the major limitation on the increase of the switching frequency which is desired for the reduction in components values and hence the size cost and the compactness of the converter. Therefore a compromise is made with the value of the switching frequency in the practically acceptable range so as to achieve the high efficiency in the converter and at the same time to and limit its cost. The reduction in the value of the switching frequency increases the size of the passive components such as the capacitors, inductors, transformers etc and makes the DC-DC converter heavier and bulky.

Soft switching techniques when employed for the power converters, helps in increasing energy conversion efficiency, shifts up the upper limit for increasing switching frequency and thereby the reduction in the size ,weight and the cost of the passive components as well as the reduction of the electrical and thermal stresses along the switching devices and the EMI reduction during switching [5]. Thus the power loss during switching is eliminated from the converter. Soft switching can be achieved by the addition of the resonant components or else by the use of the parasitic component of the converter circuit. An isolated bidirectional converter with soft switching is presented in this paper. The circuit diagram is shown in fig.1.

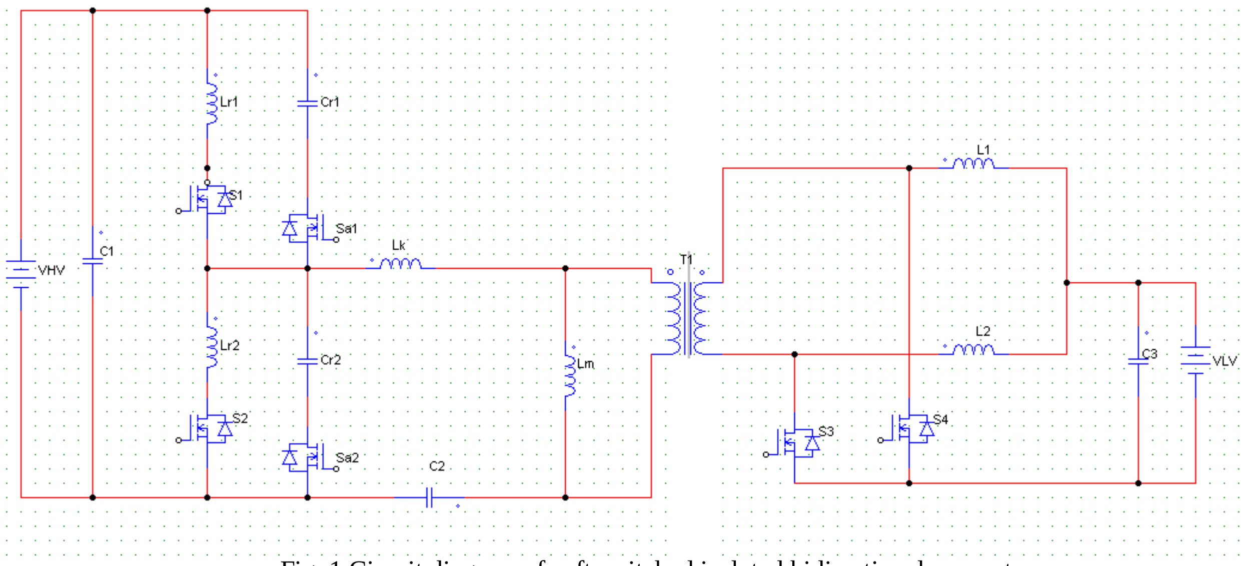


Fig. 1 Circuit diagram of soft switched isolated bidirectional converter

Soft switching is realized in the DC-DC converters circuit by the addition of the resonant switches consisting of a controlled semiconductor switch, an anti parallel external diode and a resonant capacitor or a resonant inductor. Here the Soft switching can be achieved by the either zero voltage or zero current switching condition. The condition of soft switching can only be realized in the converter circuit if the resonant part of the switch has the capability to reset itself (discharge itself) at the time of switching. If the resonant capacitor or the inductor across the switches can discharge themselves and thereby acquire zero voltage of zero current at the time of the switching, soft switching is established. Thus by the addition of the external circuit elements, the circuit can be made to operate under soft switching condition. The circuit includes high voltage $V_{HV}$, high-voltage capacitor $C_1$ and DC-blocking capacitor $C_2$, four active switches $S_1$, $S_2$, $S_3$, and $S_4$, a transformer $T_1$, two inductors $L_1$ and $L_2$, a low-voltage capacitor $C_3$, and low voltage $V_{LV}$ .The gate signals of $S_1$ and $S_2$ in the high-step-down stage are interlaced by a phase shift of 180 degree, and $S_3$ and $S_4$ are synchronous rectifiers.

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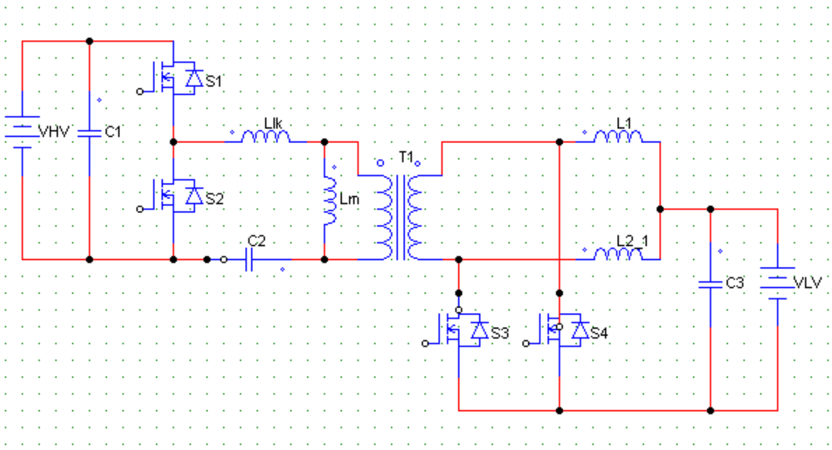


Fig. 2 Circuit diagram of isolated bidirectional converter

In the high-step-up mode, the gate signals of $S_3$ and $S_4$ are greater than 50% and are controlled by a phase shift of 180 degree. The gate signals of $S_1$ and $S_2$ are smaller than 50% and are controlled by a phase shift of 180 degree. The function of the bidirectional converter is like the double voltage step down instead of mode. (When $S_1$ is turned on, the voltage on the primary winding is reduced by half because of the capacitor $C_2$. Thus, the voltage gain can be reduced by half by adding $C_2$ in series with the half-bridge converter) This converter is controlled with duty control on frequency control so that the effect of leakage inductance can be neglected. The proposed cannot achieve zero-voltage switching on the high voltage side power switches but the low voltage side synchronous rectifier can achieve zero voltage switching. Thus, the turn ratio can be reduced as compared with the traditional half bridge converter. The size of the transformer can be decreased by using a voltage doubling circuit with low turns ratio, so that a lower turns ratio is needed on the secondary side.

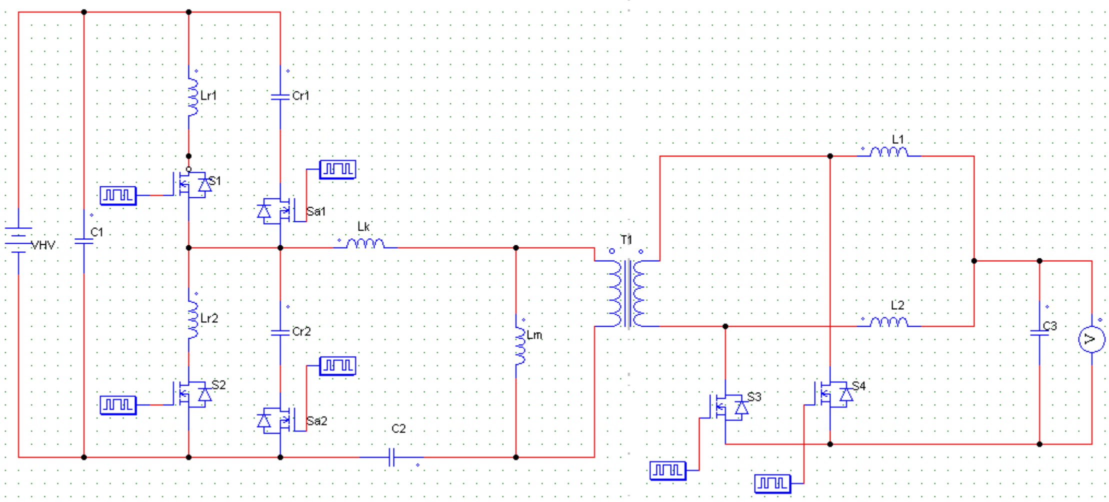


Fig. 3 Circuit diagram of soft switched isolated bidirectional converter in step down stage

The features of the converter are as follows:

1. It meets the safety standards of galvanic isolation
2. The size of the transformer can be reduced
3. The energy in the leakage inductance of the transformer can be recycled
4. It has a high conversion ratio
5. The low-voltage side has low ripple current
6. Synchronous rectifiers improve system efficiency.

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## III. RESULT AND DISCUSSION

The PSIM model for step down stage is shown in fig. 3. During the step down stage, an input voltage of 200 V is given and the corresponding voltage at the low voltage side is measured by using a voltmeter across the output capacitor. The input voltage of 200 V DC is applied at the step up side, which is shown below in fig.4. The gate signals of $S_1$ and $S_2$ in the high step-down stage are interlaced by a phase shift of 180 degree, and $S_3$ and $S_4$ are synchronous rectifiers. In the high-step-up mode, the gate signals of $S_3$ and $S_4$ are greater than 50 % and are controlled by a phase shift of 180 degree. The gate signals of $S_1$ and $S_2$ are smaller than 50 %, and are controlled by a phase shift of 180 degree with synchronous rectifiers.

During the step down stage, the voltage across the output capacitor is measured as 23.1 V. When $S_1$ is turned on, the voltage on the primary winding is reduced by half because of the capacitor $C_2$. Thus, the voltage gain can be reduced by half by adding $C_2$ in series with the half-bridge converter. The voltage across the capacitor is measured as 100 V. Fig.4 and fig.5 represents the input and output voltages of step down stage respectively. The voltage across the capacitor is shown in fig.6

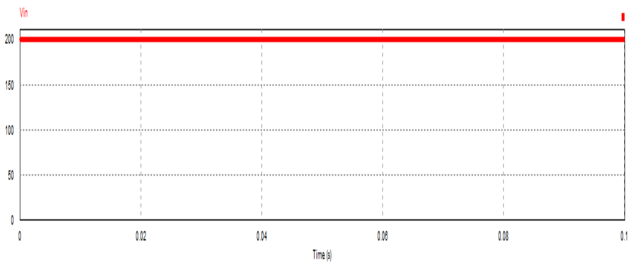

Fig. 4 Input voltage of step down stage

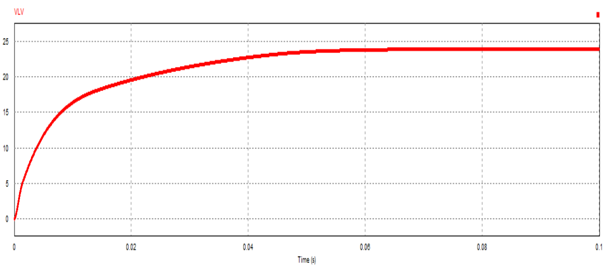

Fig. 5 Output voltage of step down stage

The presence of leakage inductance plays an important role in the conversion process since it recycles the energy stored in it to the DC blocking capacitor. The soft switching is well observed during turn off of the switches $S_1$ and $S_2$, by the provision of auxiliary switch $S_{a1}$ and $S_{a2}$ and also resonant circuit elements. The zero voltage switching of main switch $S_1$ is shown in fig.7.

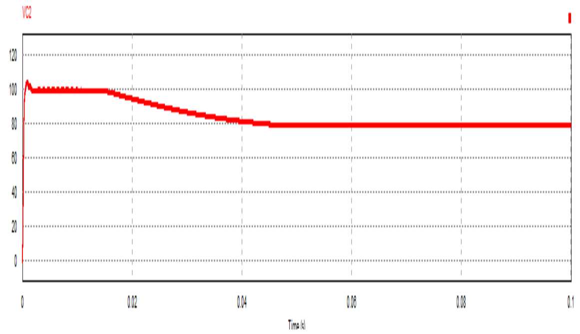

Fig. 6 Voltage across $C_2$ during step down stage

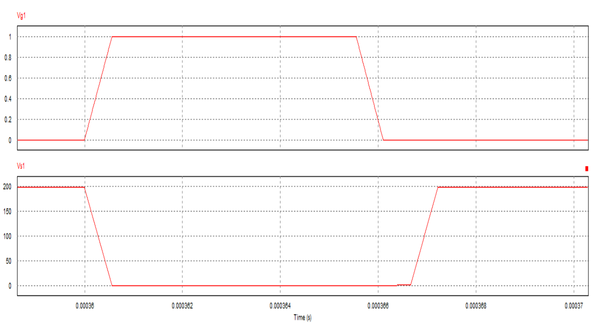

Fig. 7 ZVS turn off of the switch $S_1$

During step up stage, 24 V DC is applied at the low voltage side of the converter. The output voltage is measured almost 195 V. The DC bus voltage is usually designed as 200 V for the 110V AC power system. This is why we selected the DC bus voltage $V_{HV}$ of 200 V and the battery voltage $V_{LV}$ of 24 V. In this system, the battery needs to be charged or discharged depending on the PV power generation and the load requirement.

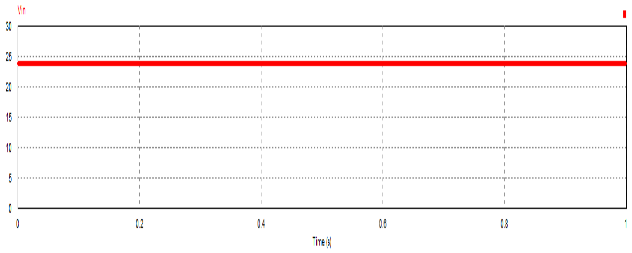

Fig. 8: Input voltage of step up stage

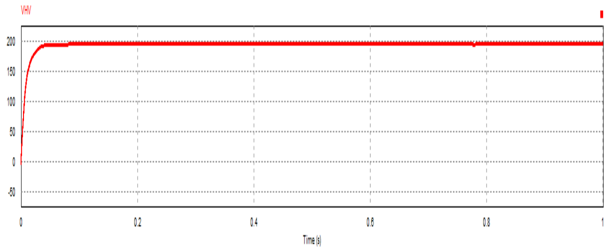

Fig. 9: Output voltage of step up stage

The low voltage (battery voltage) with 24 V can prove the high efficiency of the proposed converter. If the battery voltage is selected at 36 V or higher voltage level, the system efficiency will be higher because the conduction losses will be reduced. Fig.8 and fig.9 represents the input and output voltages of step up stage respectively.

## V. CONCLUSION

The Bidirectional DC-DC converter using with soft switching has been proposed that uses auxiliary switches and auxiliary resonant circuit. The main switches were operated under zero voltage switching condition by employing the resonant circuit. The bidirectional transfer of power is ensured with less power loss as compared to conventional converters by the provision of soft switching elements. The step down mode as well as step up mode is well verified and the ripple content at the output of both stages is observed less than 0.05%. The high frequency transformer provides a galvanic isolation between low voltage and high voltage side. In order to reduce size of bidirectional DC-DC converter, conventional topologies using hard switching method operate with high frequency. As switching frequency is getting higher, switching loss is increased. The auxiliary circuit is implemented by using soft switching method in order to overcome this drawback.

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