MANTECH Publications

Journal of Smart Grid Technology
Volume 2 Issue 2

Comparative Study of Bi Directional Converters Used In Grid Interactive Small Scale Renewable Power System

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Abstract

As the population increases and people continue to demand a higher standard of living, the demand for energy also continues to increase. Thus there is a rapid growing interest in renewable energy, such as fuel cells and photovoltaic systems in the distributed power system architecture. Innovative topologies for renewable energy conversion systems that integrate with electric grids and energy storage systems are being proposed, each with limited modes of operation for the various needs in smart grid applications. In the view of this, bidirectional power flow plays vital role in grid connected systems. In vehicle-to-grid (V2G) systems, electric vehicles interact with the grid as distributed energy storage systems that offer many potential benefits. As an energy Interface between a vehicle and the grid, the bidirectional converter plays a crucial role in their interaction. Its reliability, safety, cost, efficiency, weight, size, harmonics, and other factors are of essential importance for V2G realization, especially for on-board operations. Beyond the common existing topologies for bidirectional converter, this paper brings out a comparative study of different types of bidirectional converter which are used in grid connected systems with highlighting the features of each converter for rooftop solar generation and hybrid power system in small scale renewable generation.

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Keywords: *Bi-directional converters, battery storage, renewable energy, conversion system.*

I. INTRODUCTION

This paper discusses the usefulness of different types of converter to support bi-directional power flow in grid connected systems. The design includes a bidirectional inverter (single phase) along with a dc-dc converter interfaced with a battery bank or any renewable resources such as solar arrays, fuel cells etc. Battery bank is used when grid requires additional power to meet out load demand, battery operates in discharge mode and power is fed into the grid. When grid has surplus power, battery operates in charge mode and power is fed into the battery. During discharge mode, power is fed at unity power factor by ZVS over full line of AC voltage. In grid-connected solar photo-voltaic (PV) systems, solar energy is fed into the building loads that are connected to the grid through a service connection with surplus energy being fed into the grid and shortfall being drawn from the grid. Production of surplus energy may happen when solar energy produced exceeds the energy requirement of the building. This surplus is fed into the grid. During the night, or during the day energy demand in the building exceeds solar energy generation capacity, energy is drawn from the grid. For buildings with grid-connected solar PV systems, the service connection meter needs to be of the bidirectional type, whereby import kWh and export kWh are separately recorded. A grid-connected solar PV system consists of solar panels, solar panels mounting structure, one or more solar grid inverters, protection devices, meters, interconnection cables and switches. [4]

The schematic layout shows the grid connected solar panel with solar gird inverter without battery bank storage. The output of solar panel is not constant it varies with the day to night depending on the intensity of sun light. The storage of power with battery bank will gives reliable operation of system. This papers gives the comparative review of the different converters used in gird connected solar systems.

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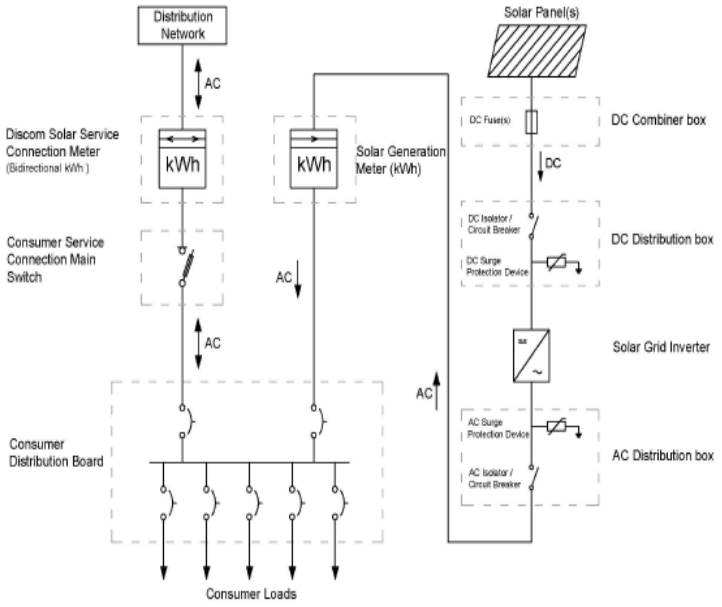


Figure: 1

II. TOPOLOGIES FOR BI-DIRECTIONAL\CONVERTERS

1.0 Single-Phase PWM Converter and Cascaded Buck-Boost DC-DC Converter

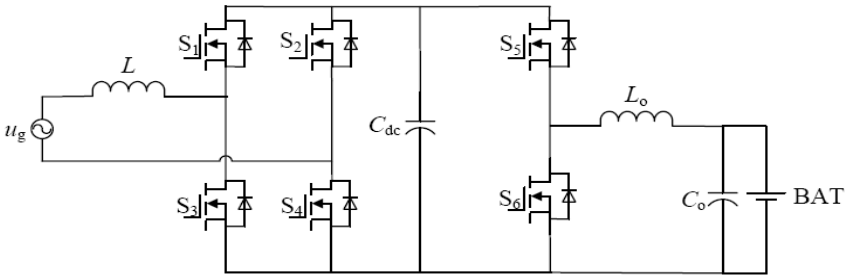


Figure: 2

The cascaded buck-boost converter allows bidirectional energy flow and overlapping input and output voltage ranges. Actually, the intermediate capacitor bank has already changed the cascaded buck-boost converter into two stages each one of which can act

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either as a buck converter or a boost converter. This will leads to better applicability to battery voltage, but higher power losses compared to the topology shown in fig. 2.

1.1 Non-Isolated On-Board Bidirectional Charger Composed Of PWM Converter And Cascaded Buck-Boost DC-DC Converter.

An integrated bidirectional charger composed of eight-switch inverter (ESI) and interleave DC-DC converter, integrating the DC/DC converter, on-board bidirectional charger, and DC-AC inverter together. The first stage of this topology can act as three-phase DC-AC inverter or single-phase PWM converter to realize traction/regenerative and charging/discharging respectively, without any relays or other switching devices to change the operating modes compared to most other integrated topologies. Accordingly, this bidirectional multi-function two-stage topology implements a complex controller and introduces significantly complications in converter design.

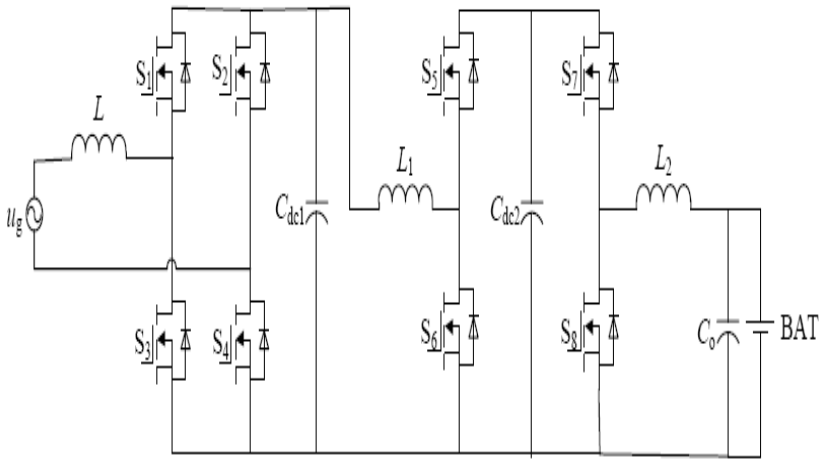


Figure: 3

2.0 Single-phase SynchroConverter

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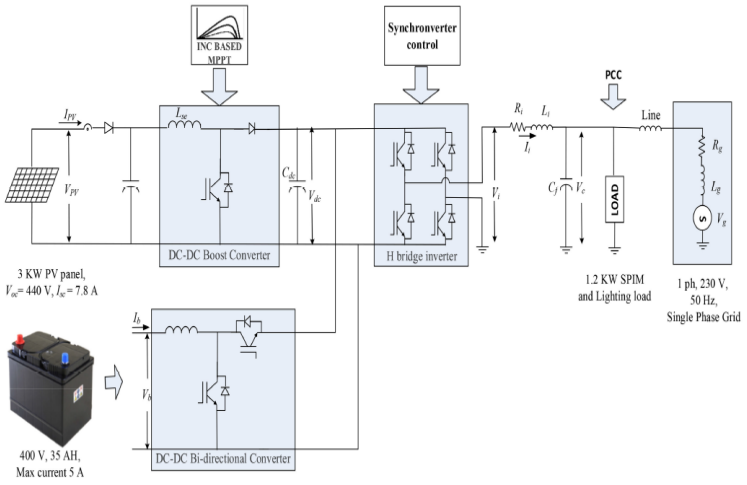


Figure: 4

A grid-connected synchronous generator pushes/absorbs real power to/ from the grid depending on the grid condition as per its governing system and inertial response. One of the fundamental challenges faced while designing the single-phase synchronverter as compared with others was the calculation of real and reactive powers from voltage and current samples. For a three-phase system, the real and reactive powers are almost constant dc quantities and hence designing the PI controller parameters is a less cumbersome task. However, in the single phase case, both the instantaneous real and reactive powers oscillate at twice the system fundamental frequency and hence a PI controller may not be able to track the reference (which is constant) satisfactorily.

In the PV system, the setting of the real power reference is straight forward and can either be set as the maximum power point (the controllability of output power will be lost) or at some lower value as requested by the grid through a smart metering scheme. However, questions may be raised regarding the reactive power reference since presently as per the grid code a PV-based system operates at unity power factor. In the near future, this unity power factor operation may get replaced by automatic voltage regulation at the point of common coupling (PCC) to help supply the local load's reactive power demand.

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An H-bridge IGBT-based single-phase inverter was used for synchronizing the PV system with the grid. The interfacing inductor and the capacitor at the output of the inverter were designed to filter out the higher-order frequency component to reduce the total harmonic distortion (THD) <5% in the system. The filter capacitor also acts as a reactive source during steady-state operation. The filter parameters are chosen based on the ripple content and operating voltage of the system. The rating of the IGBT switches is decided by the rated current carried by the grid connected single-phase inverter to mimic the behavior of a synchronous generator. This scheme has the capability to convert rooftop PV systems to an ancillary service provider thereby helping the grid during a demand–supply mismatch scenario. Furthermore, it has been shown that by introducing a Q– V droop into the inverter control loop, the inverter also supports system voltage whenever there are voltage deviations. [3]

3.0 Single phase DC/AC bi-directional converter with high- frequency isolation

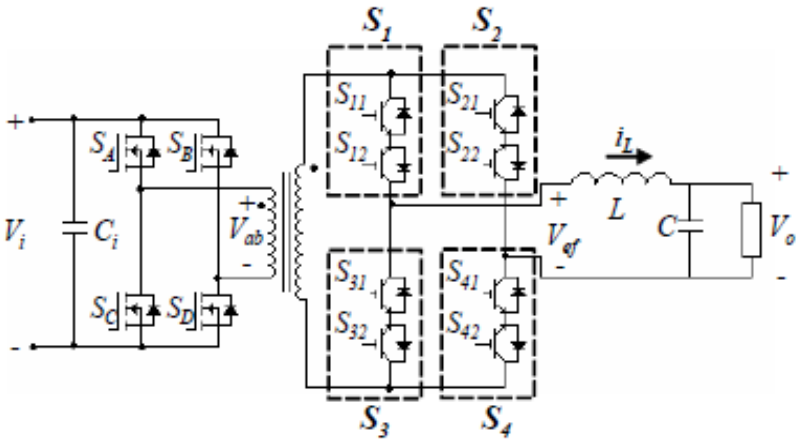


Figure: 5

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The objective of the single-phase HF-Link inverter is to generate a sinusoidal voltage with galvanic isolation and bidirectional power flow capability. The single-phase inverter generates a high-frequency ac voltage at the transformer primary. It generates a high-frequency PWM voltage by means of closed-loop bipolar control. Bipolar voltage is needed because of the use of a HF transformer.

Fig. 1 shows the basic configuration of the high-frequency link inverter. The devices SA-SD form an inverter circuit that feeds the transformer with a high-frequency ac voltage providing isolation between the dc source and the load. The devices S11-S12, S31-S32, S21-S22 and S41-S42 are bidirectional switches and form an ac/ac converter. When the energy flows from the dc source, the ac/ac converter operates as a positive or negative rectifier. The output filter eliminates the high frequency harmonics and delivers a sinusoidal voltage to the load. The load has been modeled as a resistor, but the results can be easily extended to others applications.

Table- I outlines the 4 different DC/AC converter switching states and their associated output voltage presented at primary of the transformer, Vab.

Table -II shows the 4 different AC/AC converter switching states and their associated output voltage presented at input of low-pass filter, Vef. [2]

Table-I DC/AC switching converter states

S_A	S_B	S_C	S_D	V_{ab}
ON	OFF	OFF	ON	Vi
ON	ON	OFF	OFF	0
OFF	OFF	ON	ON	0
OFF	ON	ON	OFF	-Vi

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Table-II AC/AC switching converter states

S_1	S_2	S_3	S_4	V_{ef}
ON	OFF	OFF	ON	V_{ab}
ON	ON	OFF	OFF	0
OFF	OFF	ON	ON	0
OFF	ON	ON	OFF	$-V_{ab}$

A DC/AC inverter with high-frequency isolation and bidirectional power flow capability, the benefits of this topology are: reduced number of conversion stages, no dc-link required, and bidirectional operation capability. The linear quadratic regulator LQR+I is an effective way to implement a multivariable control. The experimental results correlate perfectly with the model and its performance with small overshoot and very low steady-state error. These results show the benefits of the LQR+I control technique.

The commutation strategy must satisfy some rules:

a) A short circuit of the dc source is not permitted.

b) The current through the inductors cannot be interrupted.

c) A commutation strategy verifying these rules and taking advantage of the possibilities for soft switching is proposed.

The commutation strategy for the dc/ac converter is defined by the modulation strategy. The simulated experiment results are for output voltage

Vo = 110 Vrms, input voltage
Vi = 24 Vdc,
output power Pomax = 160 W,
output voltage frequency f = 50 Hz, fs=20kHz,
L=2mH and
C=10uF. [2]

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4.0 Two-Stage Topology Composed Of PWM Converter And Dual-Active-Bridge (DAB).

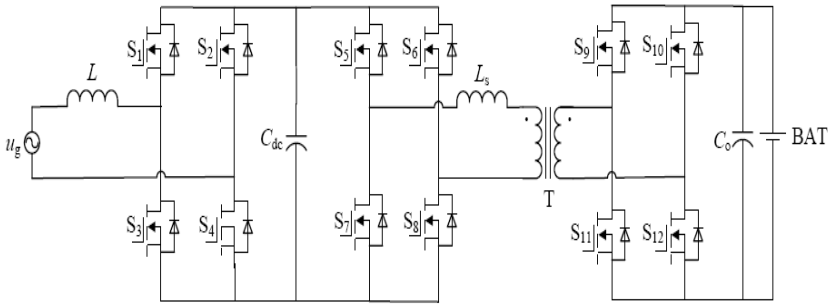


Figure: 6

A two-stage topology that consists of a single-phase PWM AC-DC converter and a dual-active-bridge (DAB) high-frequency isolated DC-DC converter This topology improves safety and reduces size of the converter. The DC-DC part in this topology is controlled by a phase shift control to achieve zero-voltage switching (ZVS) turning-ON of switchesS5–S12.Like most voltage-fed topologies, DAB converters suffer from several limitations, including high input pulsating current, limited soft-switching range, high circulating current through devices and magnetic, etc

4.1.Two-stage topology composed of PWM converter and series resonant converter (SRC)

A single-phase series resonant converter (SRC) in its high-frequency isolated DC-DC stage, The phase shift control is also used to achieve the ZVS turning-on of the four switches in the primary and the zero-current switching (ZCS) turning-off of the four switches in the secondary, as well as the bidirectional energy flow. Compared with the non-resonant DAB converter, the peak current of SRC is much higher which increases current stress of the switches and magnetics, and requires higher rating of components. Therefore, it is not preferred topology for this application. For V2G applications, contactless topologies have been proposed that use wireless energy transmission through loosely coupled transformers by resonance. These topologies offer more flexibility and convenience in charging/discharging operations.

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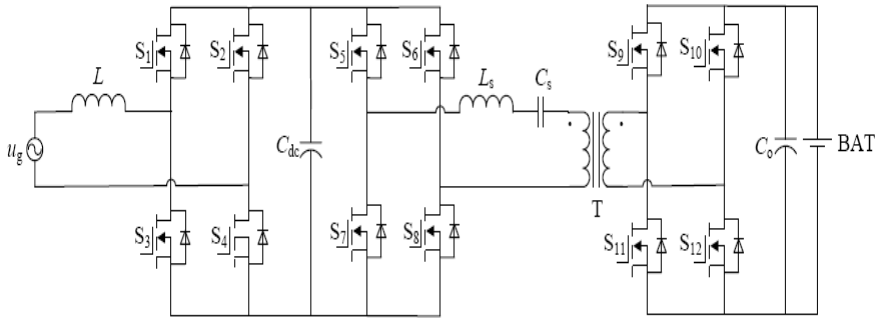


Figure: 7

4.2 Two-stage topology composed of PWM converter and inductive power transfer (IPT)

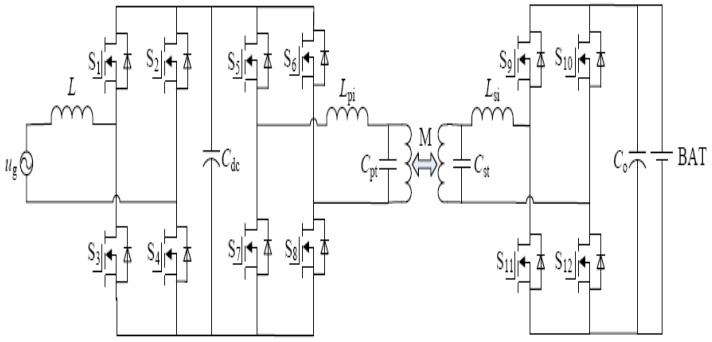


Figure: 8

A two-stage contactless topology that is composed of a single-phase PWM converter and inductive power transfer (IPT) high-frequency isolated DC-DC converter [LCL parallel resonant circuits are used to achieve ZVS turning-on of the eight switches in the DC-DC part in this topology. The output power is controlled by the angle difference between the secondary and primary voltages of the transformer. However, the transmission efficiency of the DC-DC part in this topology is low, typically about 85%, and hence does not satisfy efficiency standards of V2G applications.

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5. 0 Bidirectional single-stage topology based on matrix converter

A matrix converter based bidirectional IPT topology has been developed for V2G applications, shown in Fig. 7, in which S1–S4 are bidirectional switches. The topology uses a single-stage power conversion, eliminating the DC link to improve system efficiency. Since this topology uses only one DC capacitor, it has the apparent advantage of small size and low cost. However, the grid-side current waveforms in this topology contain high harmonic contents. [1]

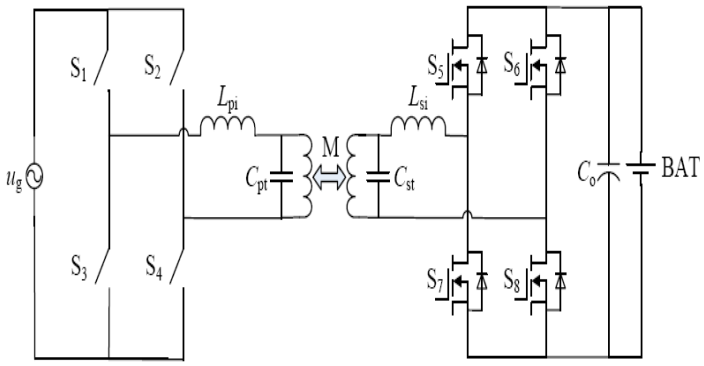


Figure: 9

5.1 Single phase Matrix Converter based Resonant Dual Active Bridge

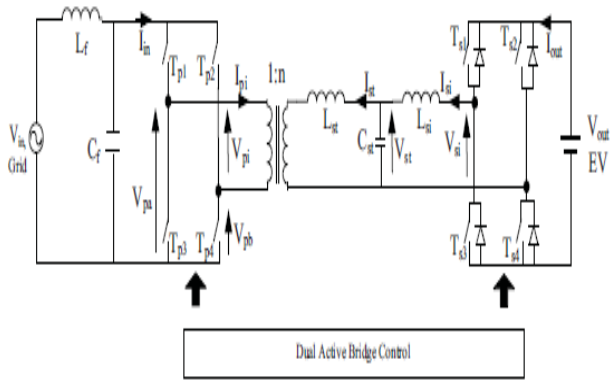


Figure: 10

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Bidirectional Inductive Power Transfer (IPT) single-stage topology based on matrix converter, primary side of this topology is a single-phase matrix converter, in which S1–S4 are bidirectional switches. Each of the bidirectional switches is composed of two reverse tied active switches. Due to grid-side current distortion created by converter operation, the input filter is necessary, and need to be well designed to comply with the power quality standards. Furthermore, its control scheme and switching commutation strategy increase the complexity of this topology. In addition, its secondary side peak current is high resulting in selection of higher power rating switches.

A matrix converter based resonant dual active bridge capable of transferring bi-directional power between the utility grid and an EV has been designed and simulated in MATLAB Simulink TM, and results are presented to verify the viability of the proposed concept. The primary side of the system is powered by a 230 Vac single-phase source and the output is connected to a 200 V battery, representing an EV or an active load. A complete set of design parameters of the simulated system. [5]

The amount of bidirectional power flow can be regulated by either controlling φ_1 and φ_2 or θ However, control through φ_1 and φ_2 while maintaining fixed θ at $\pm 90^o$, allows both converters of the system to be operated at near unity power factor when the LCL circuit is properly tuned. Therefore, modulation of Vpi and Vsi magnitudes through φ_1 and φ_2, can be regarded as the preferred mode of control, and this section details how it can be implemented to realize bi-directional power flow while ensuring a good power factor (PF) and an acceptable level of total harmonic distortion (THD) 4 % at the point of grid connection.

6.0 High Power Factor Bidirectional Single-Stage Full-Bridge Topology

Fig 11 shows the high power factor bidirectional single-stage full-bridge converter. Lis the filtering inductor; Co is the energy storage capacitor. This a high-frequency isolation transformer; and BAT is the battery pack. C1 is the dead-time capacitor whose capacitance is quite small and mainly works as the snubber capacitor during dead time in the discharging mode to absorb the remaining small inductor current, and as such a diminutive film capacitor can be used.

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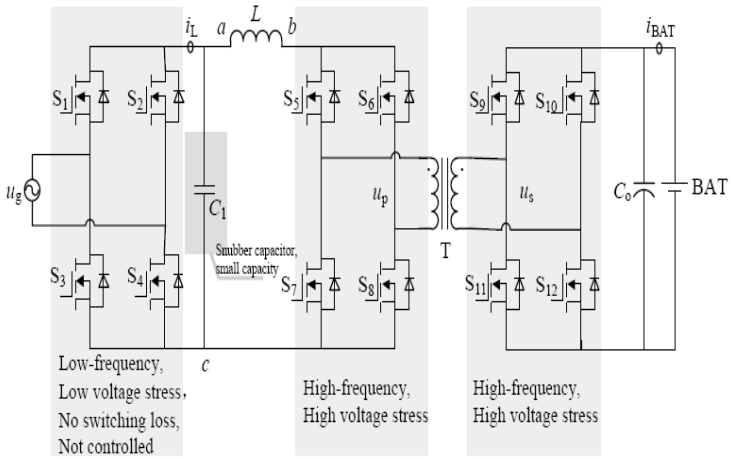


Figure: 11

This topology eliminates the bulky and expensive DC intermediate link capacitors and the resonant tank in the common two-state topologies, and employs a single-stage conversion to achieve unity power factor operation. Compared to the foregoing typical topologies, this topology contains only one inductor and one storage capacitor, has higher power density, smaller size, lighter weight, reduced cost, and improved reliability. Also losses on the passive components are reduced, making it suitable for applications to the on-board environment. Moreover, its line-frequency switching bridge (S1–S4) has no switching loss, leading to higher energy efficiency. In addition, unlike the typical two-stage topologies in which twelve switches operate in high frequency and under high voltage stress, the lower switching frequency and voltage stress of S1–S4 in this topology implies that active components of lower grade can be selected, and conduction losses and costs are lower. Finally, S1–S4 don't need to be controlled and can be driven by pulses with fixed duty cycles, further simplifying the control complexity. The relationship between the input and output can be expressed as:

$$U_0 = \frac{1}{N(1-D)} U_1$$

where $\boldsymbol{U_O}$ is the output voltage of the battery side, $\boldsymbol{U_I}$ is the rectified input voltage, $\boldsymbol{N}$ is the transformer turn ratio, and $\boldsymbol{D}$ is the duty cycle.

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In the discharging mode, S5–S8 are not driven by the pulse but rather work in the diode rectification state, while S9–S12 work alternately in accordance with the high-frequency pulses shown in Figure , and S1–S4 work alternately in accordance with the grid voltage as shown in Figure 12b. Because S1–S4 switches at the zero-crossing point of the grid voltage and current, there are no switching losses, but only conduction losses. From top to bottom in Figure 12a are the waveforms of S9 and S12's driving pulses, S10 and S11's driving pulses, the inductor current, and the secondary voltage of the transformer. Figure shows the line-frequency waveforms of this topology: (top to bottom) the waveforms of the inductor current, the driving pulses of S1 and S4, the driving pulses of S2 and S3, and the grid current. [6]

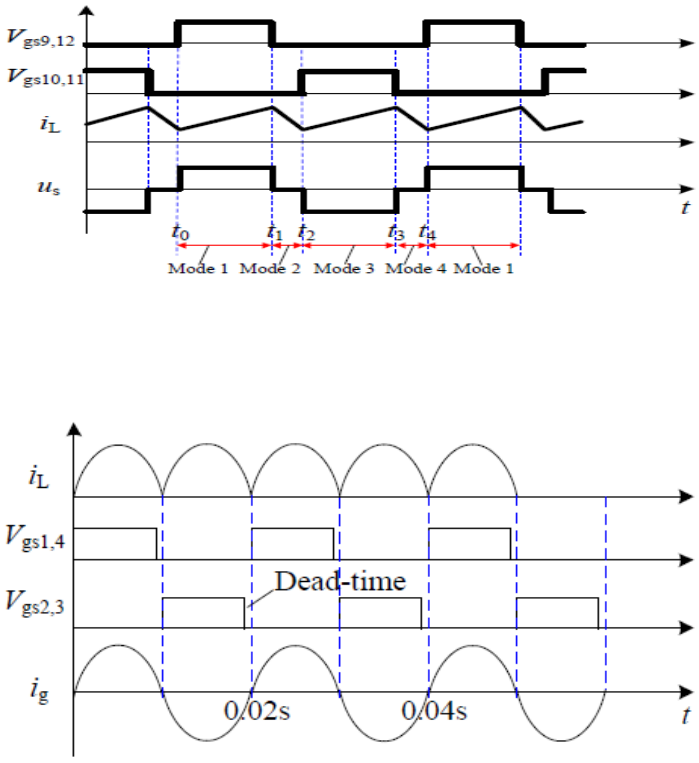


Figure: 12

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In the discharging mode, this topology is equivalent to a buck converter, and the input-output relationship can be expressed as:

$$U_0 = \frac{1}{ND} U_1$$

In both the charging and discharging modes, unlike other typical topologies for which there is a Specific range or condition for soft-switching, the BSS-FBC has only four active switches operating at high frequency and only one stage from the aspect of control, resulting in simplified control design and implementation. [6]

III SUMMARY AND DISCUSSION

As discussed earlier due to the concept of smart grid, the Distribution system will have more than one feeding node or Voltage controlled bus. Also in future power flow may be bidirectional due small scale distributed generation. In the view of those bidirectional converters plays vital role in power flow control in the distribution system. In this review some important single phase bidirectional converter are discussed. And their performances are summaries in the Table 3.

Table: 3

Converters	Efficiency	THD	Power flow control	Switching losses
Single-Phase PWM Converter And Cascaded Buck-Boost DC-DC Converter	< 80%	---	Better	more
Single-phase Synchro Converter	85 %	<5%	less	less
Single phase DC/AC bi-directional converter with	85%	--	less	less

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high frequency isolation				
Two-Stage Topology Composed Of PWM Converter And Dual-Active-Bridge (DAB)	85%	---	less	less
Single phase Matrix Converter based Resonant Dual Active Bridge	89%	4 %	better	less
High PF Bidirectional Single-Stage Full-Bridge Topology	> 90%	< 5%	better	less

CONCLUSION

The purpose of this review was to view the performance of different bidirectional converter for grid connected system. The research in past years highlighted the importance of each bidirectional topologies with their merits and demerits. Among them High Power Factor Bidirectional Single-Stage Full-Bridge Topology concept is promising topology being applied to grid connected system it has many advantages compare to other converter

Topologies. The features of this converter topology are Higher Power Density, Reduced Component count, Smaller Size, Lighter Weight, Less Harmonics Excellent Dynamic Characteristics, Increased Reliability, Simpler Control, and Reduced Complexity etc. This feature is unique among the converters and finds its justification for the same.

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