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Modeling and Simulation of Residential Microgrid Application Integrated with Full-Bridge-Forwad DC-DC Converter

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Abstract

This paper proposes a novel topology using the photovoltaic (PV) cell based application of the microgrid to show the grid voltage. The integrated converter topology for interfacing between the dc bus and energy storage system of microgrid. The integrated full-bridge-forward dc-dc converter presents the following features: high voltage ratio, bidirectional power flow, galvanic isolation, and most important one is low number of active devices compared to the previously used to similar applications. The converter can be approached detailed including three different types of clamping circuits which are compared with each circuit. The structure and operating principle, Dual active bridge converter comparison and experimental results of the proposed topology are presented.

Index Terms— Three level inverter, photovoltaic generation, dc-dc converter, energy storage system, microgrid.

I.INTRODUCTION

Now a day's electrical energy consumption has been considerably increasing in recent years. The population growth has direct influence towards this fact. Therefore, it is essential to increase the electric power generation. Besides, once fossil fuels produce enormous amount of pollution and are becoming scarce, other sources for electric power generation, mainly clean and Renewable ones have been receiving more attention and importance lately.

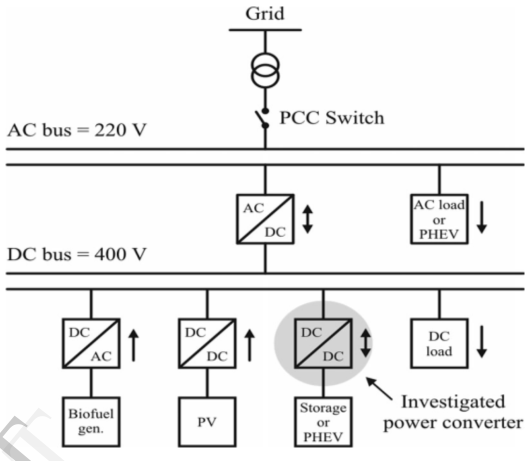


Fig.1. Residential microgrid system under study

. To increase the large amount of energy go for Distribution generation, DG units had some disadvantages to reduce such problems. The microgrid concept has been gaining more notoriety each day [1]. Some advantages of the microgrids are the possibility to generate electric power with lower environmental impact and easier connection of these sources to the utility, including the power management capability among their elements. Regarding the connection methods of the distributed energy sources, energy storage devices, and loads in a microgrid, the dc bus is the simplest interconnection bus [2]. This configuration results in high efficiency, high reliability, and no frequency or phase control requirements, when compared to the ac interconnection bus [5]. Moreover, it has low distribution and transmission losses, low cost, the possibility to operate across long distances, and it does not use transformers, in turn leading to volume and cost reduction.

In the microgrid systems, the energy storage system is of great importance. It is responsible for supplying energy to the loads when the main sources are not capable during short periods of time and steady-state operation. The proposed residential microgrid energy storage system composed of a battery bank and a super capacitor bank of the microgrid energy storage system.

The DAB converter which is the most use topology for this application, [1] it needs an elevated number of active devices thereby resulting in high cost. It also presents a high input and output current ripple, A dc–dc bidirectional converter can be added between the energy storage device and one of the full-bridges [3][6] it provides advantages, such as to extend the battery lifetime by maintaining the supplied current with a low ripple.

II. PROPOSED INTEGRATED FULL-BRIDGE-FORWARD DC–DC CONVERTER

The proposed dc–dc converter, shown in Fig. 2, is the integration of a full-bridge and a forward converter. The

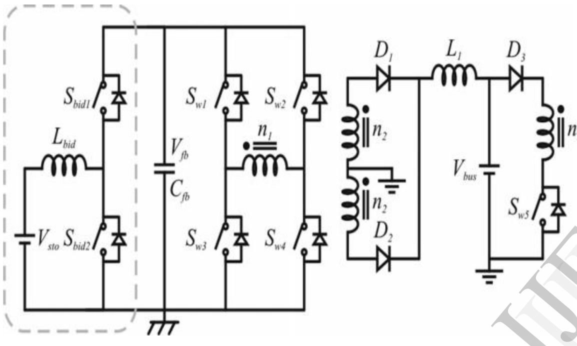


Fig.2. Proposed integrated full-bridge-forward dc–dc converter including a bidirectional converter.

Full bridge converter is responsible for the energy storage system discharging stage, while the forward converter is responsible for the energy storage system charging stage in the microgrid system this forward converter resultant by the integration process is called a double ended forward converter.

A three-winding transformer is required in this topology. Windings 1 and 2 are used in the full-bridge operation, and windings 1 and 3 in the forward operation. One diode needs to be added in series with the transformer tertiary winding to avoid current circulation through the ant parallel diode of the forward converter switch during full-bridge converter operation mode.

A. Proposed Converter Including Dissipative Passive Clamping Circuit

In order to avoid voltage spikes during the turn-off of the forward converter active switch due to the interruption of the current through the transformer leakage inductance, one passive clamping circuit is first added in parallel to this switch. This clamping circuit is composed of one diode, one capacitor, and one resistor, as shown in Fig. 3. Moreover, this circuit plays a role in the transformer demagnetizing process, once the clamping voltage is applied on the transformer tertiary winding during two operation subintervals and a certain amount of current circulates through it.

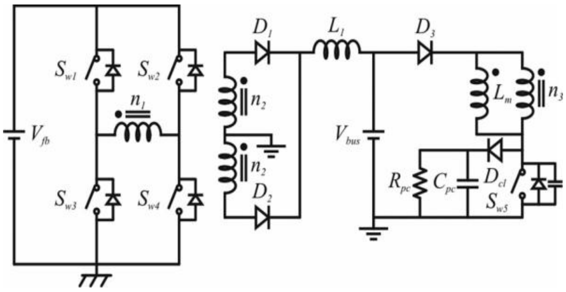


Fig.3. Proposed converter with dissipative passive Clamping circuit.

This topology solves the voltage spike problem. However, during the clamping circuit on state, the magnetizing inductance current is deviated toward the passive elements. This process imposes power losses on the topology, which reduce the converter efficiency.

The power losses can be reduced as the clamping circuit voltage and the transformer magnetizing inductance become higher, as well as the transformer leakage inductance becomes lower. This occurs because the inversion of the current through the transformer primary winding occurs more quickly, reducing the amount of energy deviated toward the passive clamping circuit.

Another way to improve the efficiency of the double-ended forward converter is using different types of clamping circuits. Two new topologies are proposed: a regenerative passive clamping circuit, presented in Section II-B, and a regenerative active clamping circuit, shown in Section II-C.

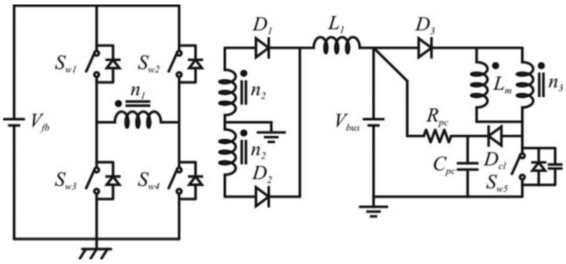


Fig.4. Proposed converter with regenerative passive clamping circuit.

B. Proposed Converter Including Regenerative Passive Clamping

Using the same components of the dissipative passive clamping circuit shown in Fig. 3 and changing one of the resistor connection points, as shown in Fig. 4, it is possible to modify the clamping circuit in such a way that part of the deviated energy is regenerated back to the microgrid dc bus and a smaller part is dissipated over the resistor. Compared to the converter topology with dissipative passive clamping, for the same resistor value, the voltage across the clamping capacitor in this new topology increases, but the average voltage across the resistor is lower. These results are obtained through converter simulation.

C. Proposed Converter Including Regenerative Active Clamping

One alternative for reducing the losses over the clamping circuit even more is to use a regenerative active clamping circuit. For the double-ended forward topology under study special attention should be taken, since the active clamping circuit cannot regenerate energy to the microgrid dc bus through the transformer tertiary winding due to the presence of the series diode, thus eliminating the possibility of use of some traditional active clamping circuits.

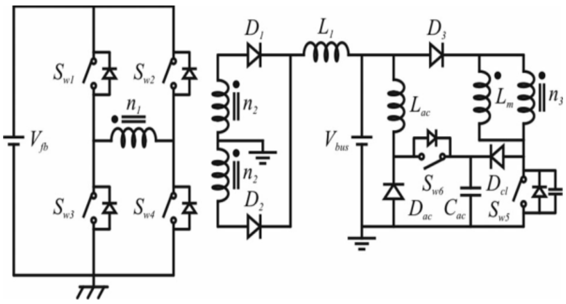


Fig.5.Proposed converter with regenerative Active clamping circuit.

Considering this fact, the proposed forward converter with an active clamping topology is shown in Fig.5.Basically; the clamping resistor is replaced by an active switch, a diode, and an inductor.

The energy stored in the clamping capacitor due to the current iDcl is delivered back to the dc bus, instead of being dissipated over a resistor. The active clamping circuit switch can be turned ON during any forward converter operation stage. The switch on time (duty cycle) is an important factor to determine the voltage level across the clamping circuit. The lower the switch on time, the higher the clamping circuit voltage and, consequently, a lower portion of energy is deviated toward the clamping circuit, reducing the switching and conduction losses on this circuit, and increasing the converter efficiency. In this converter, there are two additional operation stages. One in which the clamping circuit current circulates through *Sw*6 and *L*ac , and another in which the current circulates through *D*ac and *L*ac. The transformer design methodology is briefly discussed in [1].

TABLE I
CONVERTERS' COMPARISON

parameters	DAB	DAB + bidirectional	FB-Forward + bidirectional
Active switches	8	10	7or8(with active clamping)
inductors	0	1	2
Transformer turns ratio	1:6	1:6	1:6:7
Input voltage	100	80	80
Output voltage	200	365	400
Bi-directional power flow	No	yes	yes

III. COMPARISON BETWEEN DAB AND PROPOSED CONVERTER

The main objective of this section is to compare the proposed topology with the most used and consolidated converter for similar applications, which is the DAB converter. The DAB converter, DAB including a bidirectional converter, and the proposed converter including a bidirectional converter are compared in Table I in terms of number of devices, voltage levels at the input, output, transformer, and active switches of the converters operating at nominal power.

In order to make a fair comparison, the transformer turns ratio *n*1:*n*2 and operation frequency have been chosen to be the same. Moreover, the parameter known as *d*, given by equation 1, has been kept near to 1 for the three converters. This brings advantages mainly for the DAB converter operation, since it guarantees a wider power range with ZVS wider power range with ZVS and lower ripple levels for the currents through the converter input, output, transformer, and active switches. The transformer leakage inductance had to be increased for both DAB converters to adjust the input and output voltage levels, maintaining *d* near to 1. Values from Table III have been obtained employing conventional phase-shift modulation for the DAB converters at nominal power, since it is easy to implement, allows ZVS operation, has higher power transfer capability compared to triangular and trapezoidal modulations and provides lower RMS current both in transformer and the switches and causes a lower peak current compared to the aforementioned modulation schemes

$$d = \frac{n_1 V_{\text{out}}}{n_2 V_{\text{in}}}. \qquad 1$$

The transformer volume is practically the same for the three converters. The core volume is the same. The cooper volume is almost the same because the turns ratio is equal, but the current levels through DAB and DAB with a bidirectional converter are Higher than in the proposed converter, demanding more parallel wires, while the proposed converter demands an additional Tertiary winding designed for small charging current.

The proposed converter presents lesser number of active devices than the DAB converters, but more passive devices. However, it is important to highlight that the two inductors provide considerably low input and output currents ripple. The proposed converter input voltage is low and its output voltage is high When compared to the DAB converter transformer turns ratio, bidirectional power flow is possible and its voltage gain is same. Proposed converter had better efficiency to that of DAB converter.

IV PROPOSED CONVERTER INCLUDING PV CELL BASED MICRO GRID APPLICATION

The general block diagram of pv cell based residential microgrid application as shown in the figure 6.

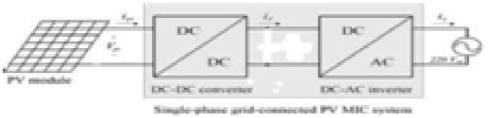


Fig.6. proposed converter including pv cell based micro grid application.

The equivalent circuit of a PV cell is shown in Fig. 6(a).

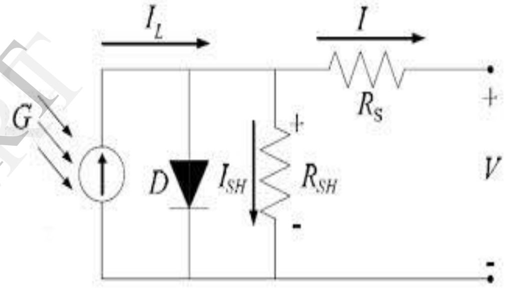


Fig.6 (a).equivalent circuit of a pv cell

It includes a current source, a diode, a series Resistance and a shunt resistance. In view of that, the current to the load can be given as: In this equation, *Iph* is the photocurrent, *Is* is the reverse saturation current of the diode, *q* is the electron charge, *V* is the voltage across the diode, *K* is the Boltzmann's constant, *T* is the junction temperature, *N* is the ideality factor of the diode, and *Rs* and *Rsh* are the series and shunt resistors of the cell, respectively.

As a result, the complete physical behavior of the PV cell is in relation with *Iph, Is, Rs* and *Rsh* from one hand and with two environmental parameters as the temperature and the solar radiation from the other hand.

$$I = I_{ph} - I_s\left(\exp\frac{q(V + R_s I)}{NKT} - 1\right) - \frac{(V + R_s I)}{R_{sh}} \qquad 2$$

In this proposed circuit using physical component method topology dc source voltage boost and inverter output is given to the single phase grid connection. By using control circuit to minimize the errors at the grid side voltage finally it gives the pure sinusoidal waveforms and the corresponding mat lab circuit are shown in the figure 7 and 8.

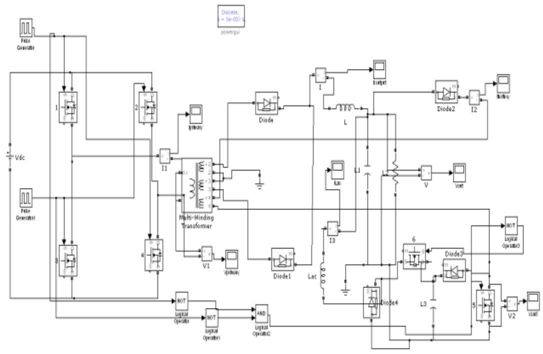


Fig.7.Full bridge forward converter including regenerative active clamping circuit.

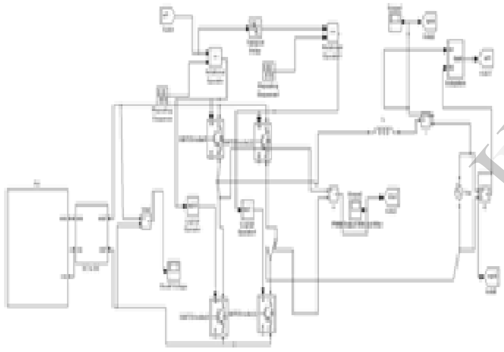
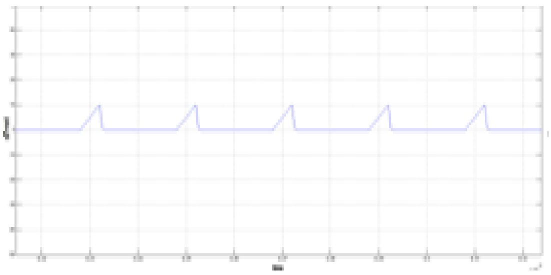


Fig. 8. Proposed converter including pv cell based micro grid application

V SIMULATION RESULTS



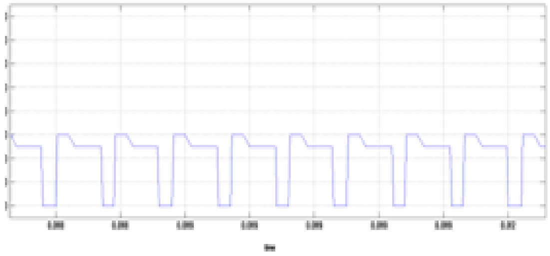


Fig.8. Current on tertiary winding and forward Converter switch voltage

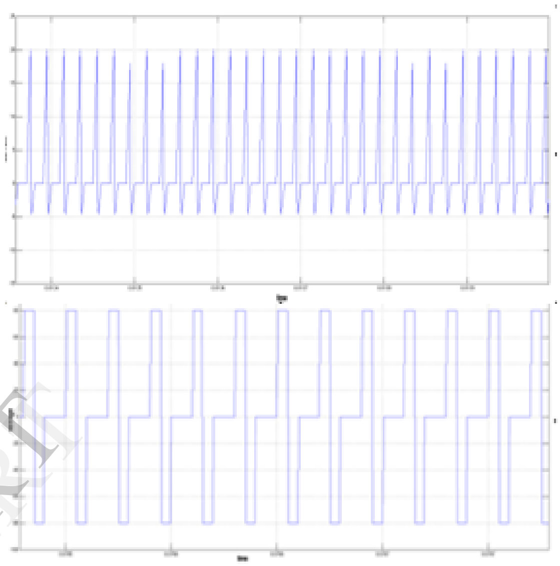


Fig.9. Current and voltage on transformer primary winding.

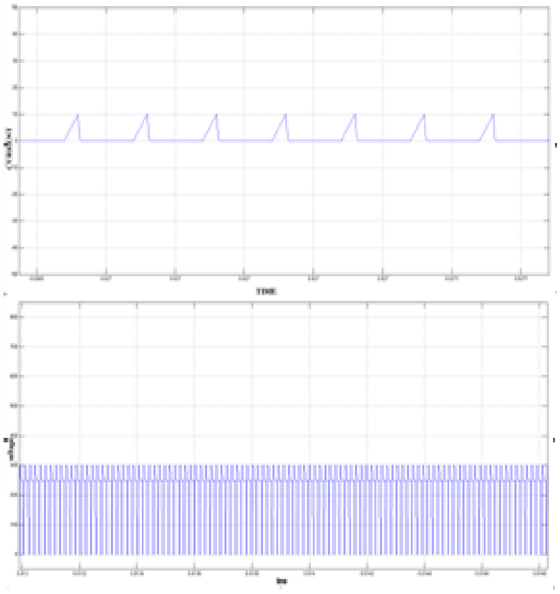


Fig. 10. Current on tertiary winding and forward Converter switch voltage

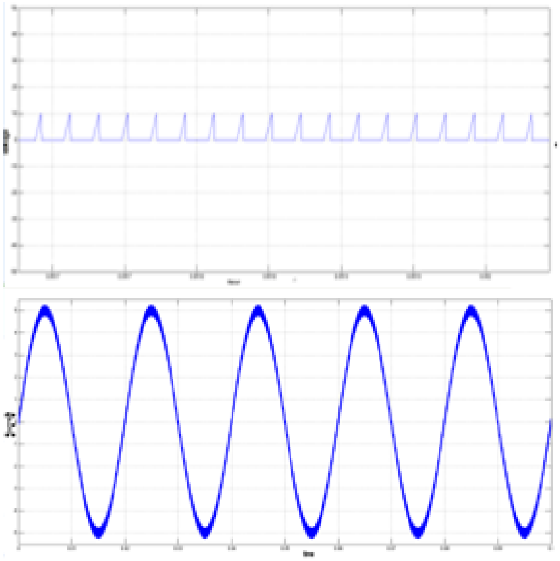


Fig. 11. Currents through the dc bus (1 A/div.) and clamping circuit inductor (200 mA/div.).

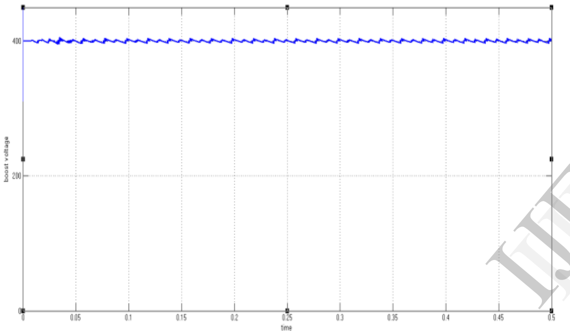


Fig. 12. Dc-Dc converter boost voltage

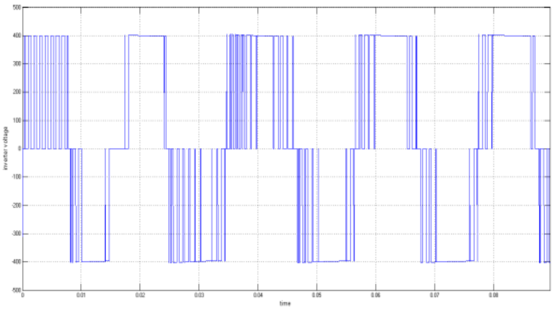


Fig.13. Three level inverter output voltage

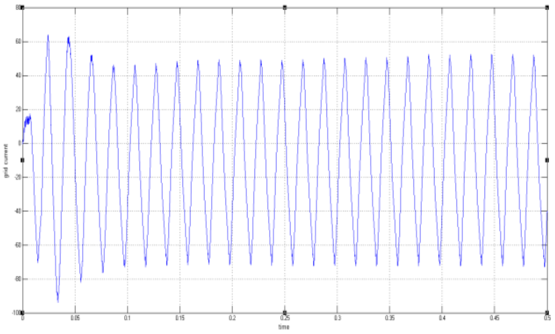


Fig.14. Grid current

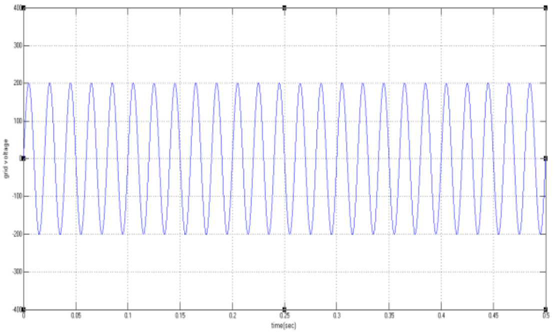


Fig.15. Grid voltage

VI CONCLUSION

This paper describes the integrated full-bridge-forward dc–dc converter to connect the energy storage system to the dc bus of a residential microgrid. The converter major advantages are reduced active switches compared to the DAB converter and individual topologies, high usage of the super capacitor bank stored energy, and a long battery bank lifetime. The proposed topology presents low input and output current ripple, high voltage ratio, high power operation on the discharging process, galvanic isolation, and bidirectional power flow.

Three different clamping circuits (dissipative passive, regenerative passive and regenerative active) are studied. As an Application of microgrid Single phase PV cell power generation is given to the grid through the boost voltage of the regenerative active clamping circuit and corresponding simulation results are shown.

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