

2 Transistors + 2 Diodes-based PEBB Designed for General Applications in Power Electronics

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Abstract

This paper presents a new Power Electronic Building Block (PEBB) designed to facilitate the implementation of different power converter topologies. The proposed PEBB consists of two diodes and two transistors and it can be used to implement the most relevant power converter topologies, due to its modularity. The addition of the two diodes is an exclusive feature of the new PEBB, which permits to implement neutral point clamped (NPC) multilevel converters. The application of the PEBB to build a three-level NPC converter and a dc-dc push-pull converter is presented and detailed in the paper, and demonstrate that the presented PEBB can be useful to shorten converter development times.

Introduction

Building a converter from scratch can require a considerable time, so new designs for rapid prototyping of power converters are always welcome. The PEBB concept, see [1]-[3], may be used to solve this problem. PEBB-based designs permit building power converters saving implementation time (rapid prototyping) and reducing cost. This is basically due to the fact that an important part of the converter has already been designed in the PEBBs.

The PEBB design presented in this paper allows implementing the majority of the most relevant power converter topologies. It consists of two transistors and two diodes with no electrical connections among them. The PEBBs can then be mounted on a motherboard to create the desired converter topology. It is worth mentioning that this PEBB has been designed to be used in control and PWM research and educational applications, so the power rating of the module is relatively small (in the order of a few kilowatts). However, this concept could be scalable to higher power ratings.

The paper is organized as follows. In the second section the design of the proposed PEBB is presented. In the third section, it is explained one of the main advantages of the new PEBB, its modularity. In the fourth section, experimental results of two converters based on the new PEBB design are presented to verify the good performance of the PEBB. Finally, main conclusions are summarized in the last section.

Design of the 2T2D PEBB

The proposed PEBB is a highly compact, highly reliable and efficient low-voltage design. As mentioned in the previous section, the new PEBB presents four semiconductors: two transistors, (which could be IGBTs or MOSFETs) and two diodes. It is due to these elements that the module has

been called 2T2D PEBB (2 Transistors and 2 Diodes). Some PEBBs with two transistors have been already designed, see [4], [5], but this PEBB includes two extra diodes in addition to the anti-parallel diodes of the transistors. The inclusion of these additional diodes is a particularity of the presented PEBB, which permits to implement neutral point clamped (NPC) multilevel converter topologies [6] and matrix converters [7].

The two diodes and the two transistors are replaceable, so it is possible to use the semiconductor which better adapts to the needs of the designed converter. The only requirement for the semiconductors is its package, which must be TO-220. The semiconductors are not interconnected within the PEBB. The connexions are defined in a motherboard to achieve the desired topology.

As well as the semiconductors, other components, such as the two single channel drivers of each transistor and the isolated power supplies of each driver, have been incorporated into the new design. The module includes also other elements for loss dissipation, such as the heat sink and the cooling fan. Fig.1 shows a block diagram of the 2T2D PEBB.

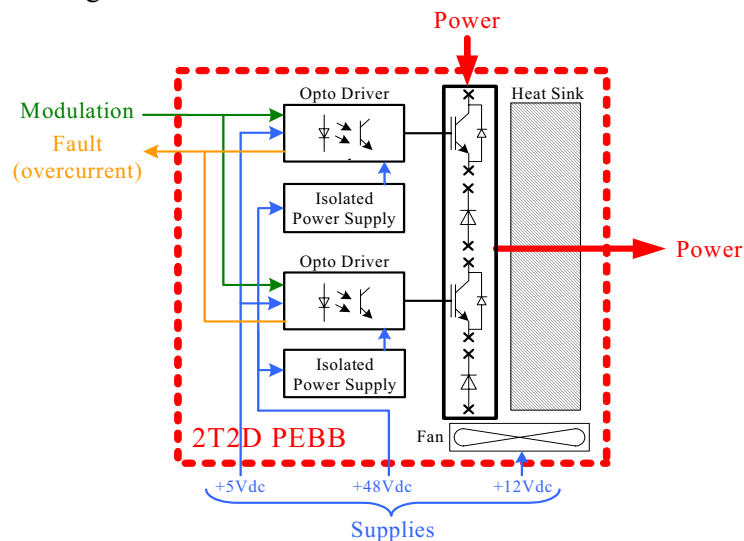


Fig. 1: Block diagram of the 2T2D PEBB (the transistors could be IGBTs or MOSFETs)

The selected driver is the HCPL-316J, which provides isolation between the input and the output (opto driver). This isolation is essential to avoid short circuits in some converter designs. Each driver needs one isolated supply. This is achieved by means of two isolated power supplies TEL 2-4823 of TRACO POWER in the PEBB, one for each driver.

In addition to the isolation, the selected driver includes some interesting features, such as the Under Voltage Lock-Out (UVLO) protection and the desaturation detection (DESAT) for protecting it against overcurrents and shortcircuits. DESAT and UVLO features work concurrently to ensure transistors protection. The driver presents a fault pin, which is activated in case of desaturation.

The selected heatsink has a thermal resistance under natural convection of 3.3°C/W. With the inclusion of the cooling fan, the thermal resistance under forced convection is about 1°C/W. This thermal resistance allows the PEBB to rate a few kilowatts of power. Furthermore, clips are used, which ensure a better heat conduction than screws. The exact power rating of the PEBB depends on the semiconductors used and the operating conditions. Calculations made in specific conditions prove that the module may process approximately 4kW.

Power Pole connectors of Anderson Power Products have been selected for power connexions. These connectors are very practical and allow up to 30A of current.

Fig. 2 shows two different views of the new PEBB design.

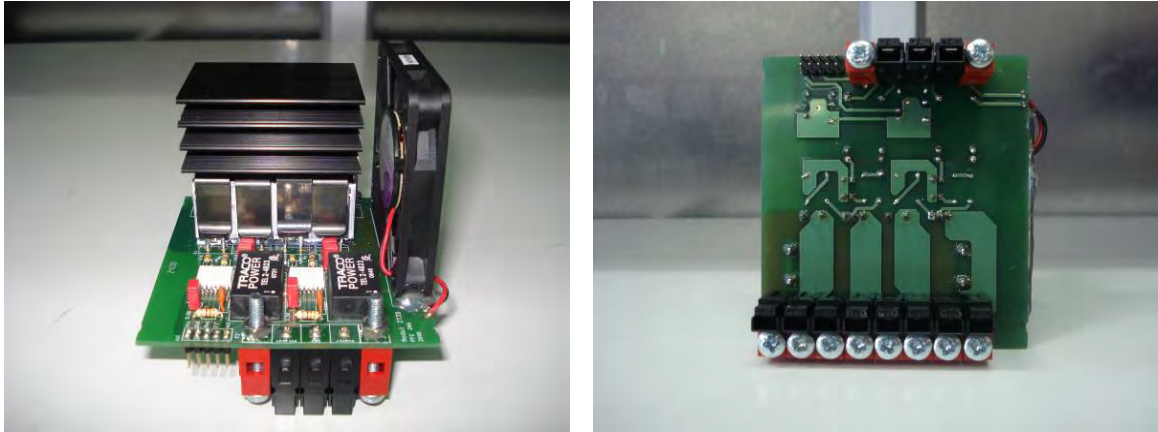


Fig. 2: Frontal and bottom view of the 2T2D PEBB

PEBB modularity

One of the main advantages of this PEBB is its modularity. The possibility of interconnecting the two diodes and the two transistors in a motherboard in the way decided by the designer permits to create the most important converter topologies. The desired converter topology is achieved by choosing the proper quantity of PEBBs and implementing the correct interconnection.

An analysis of the most relevant converter topologies has been done to decide which would be the optimal configuration for the module (i.e., number of diodes and transistors).

Some converters only need one or two transistors to be implemented (push-pull converter, half-bridge voltage source inverter (VSI), fly-back, etc). Other topologies can be implemented using some groups of two transistors (full-bridge VSI, three-phase VSI, etc.). All these converters can be implemented with a module with only two transistors (without the utilization of the two extra diodes). Fig. 3 shows how to implement different converter topologies for which the use of the two additional diodes included in the module is not required. PEBBs are marked in red discontinuous squares.

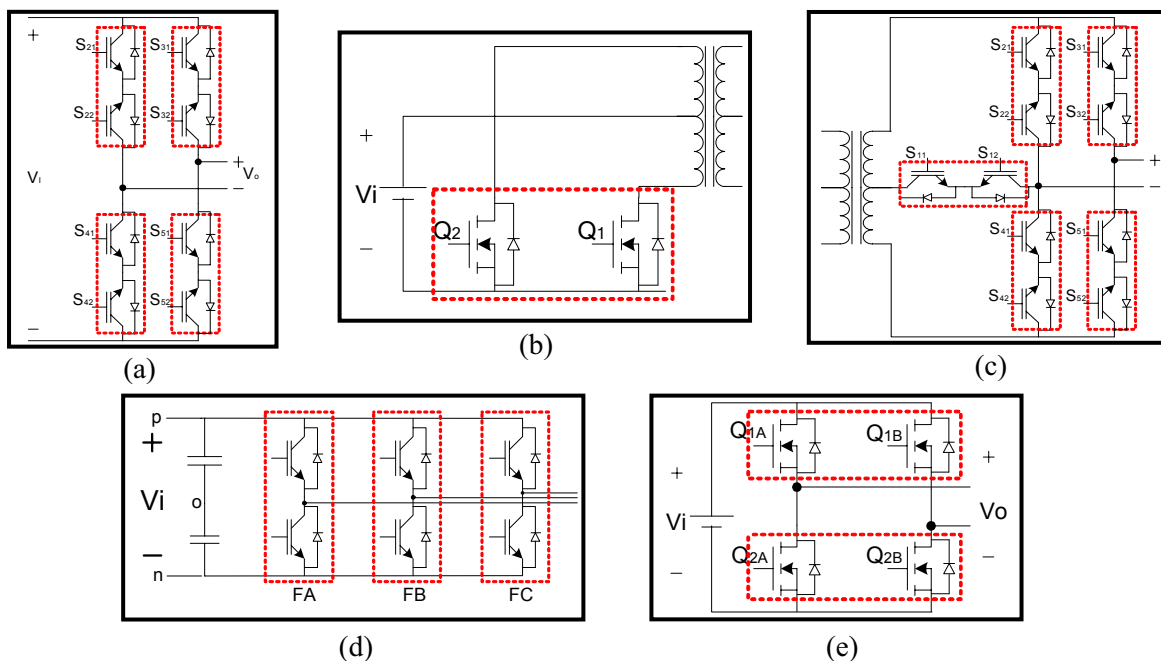


Fig. 3: Different converter topologies implemented by the utilization of 2T2D PEBBs. (a) Bi-directional single-phase VSI. (b) Push-pull converter. (c) ac-ac bi-directional three-level converter [8]. (d) Three-phase VSI. (e) Single-phase full-bridge VSI.

The two additional diodes are used in the PEBB to build neutral point clamped (NPC) multilevel converters and matrix converters.

For designing a NPC inverter of n levels ($n > 2$), $2n-2$ transistors and $2n-4$ diodes are required. It is due to this relation that the two extra diodes are necessary in the PEBB to implement NPC converters. To implement an n -level converter, there are necessary $n-1$ 2T2D PEBBs. One of the modules wouldn't use the two diodes, but the rest of them do. A PEBB including one extra diode has already been constructed [9]. That module can be used to design a three-level NPC inverter, but it is not useful to implement diode-clamped converters of more than three levels. However, it is actually possible using the 2T2D PEBB. Fig. 4 shows how to implement NPC converters with the 2T2D PEBBs.

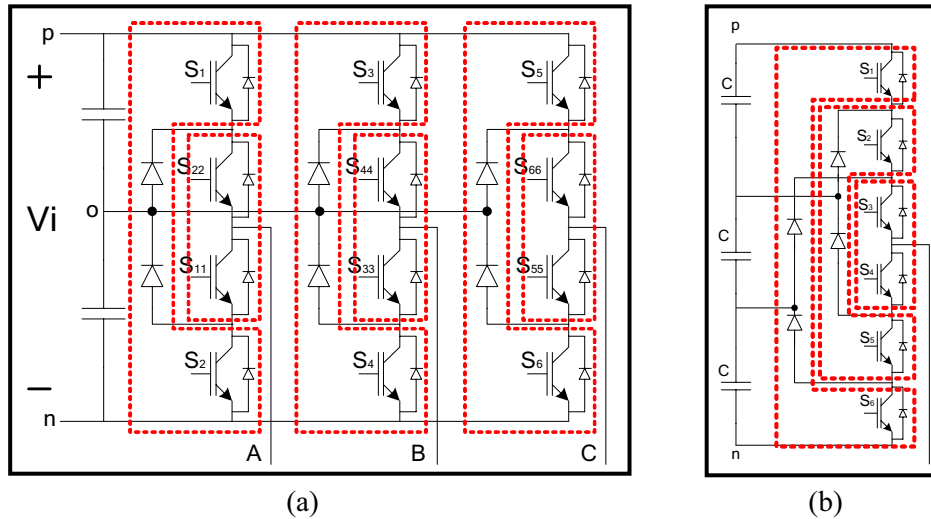


Fig. 4: NPC inverters implemented by the utilization of 2T2D PEBBs. (a) Three-phase three-level NPC inverter. (b) Single-phase four-level NPC inverter.

The matrix converter is an array of controlled and bi-directional semiconductor switching cells [7]. Most common switching configurations could be implemented by the 2T2D PEBB. Some of them can be implemented thanks to the two additional diodes of the PEBB. Fig. 5 depicts some examples:

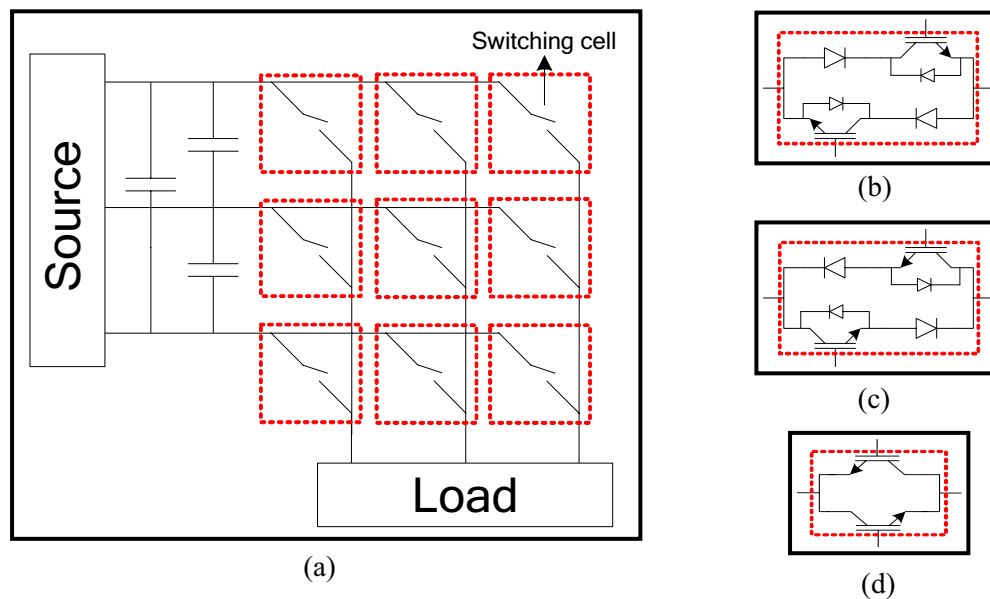


Fig. 5: Matrix converter and different switching cells implemented by the utilization of 2T2D PEBBs. (a) Matrix converter. (b) (c) Back to back switching cells that could be implemented by the 2T2D PEBB thanks to the two additional diodes. (d) Back to back switching cell without diodes.

Experimental results

In order to verify the operation and to evaluate the performance of the new PEBB design, experimental tests have been conducted. Two converters built with these PEBBs have been tested: a three-phase three-level NPC inverter and a Push-Pull dc-dc converter. The main results are summarized in the following subsections.

Three-phase three-level NPC inverter

Six 2T2D PEBBs are required to implement a three-phase three-level NPC, two for each phase. As shown in Fig. 6, one of them uses two diodes and two transistors, whereas the other one only uses two transistors.

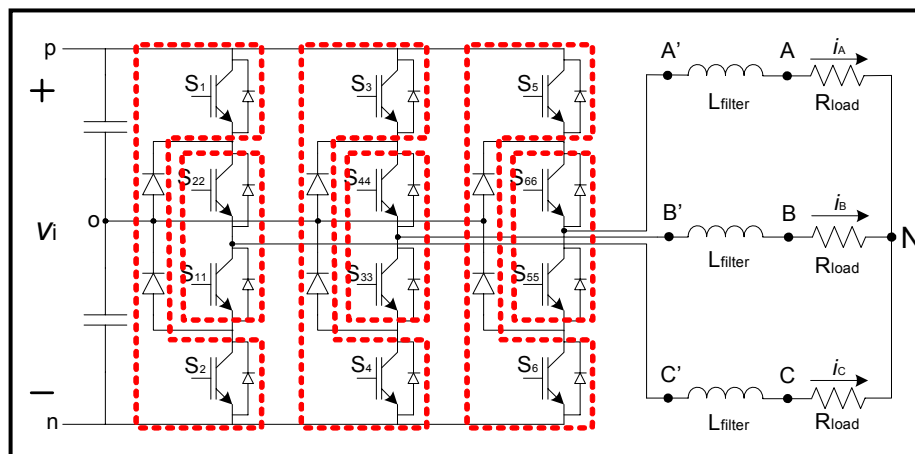


Fig. 6: Three-phase three-level NPC inverter based on 2T2D PEBBs

Fig. 7 presents the block diagram of the layout of the inverter, which includes:

- A conventional Power Supply (Transformer + bridge rectifier + capacitor) which generates 48Vdc for isolated power supplies of the PEBBs.
- A dc-dc converter, which generates 12Vdc for the fans.
- Three capacitor stages to ensure the dc voltage bus balanced.
- Six 2T2D PEBBs.
- Modulation, supply, fault and power buses.

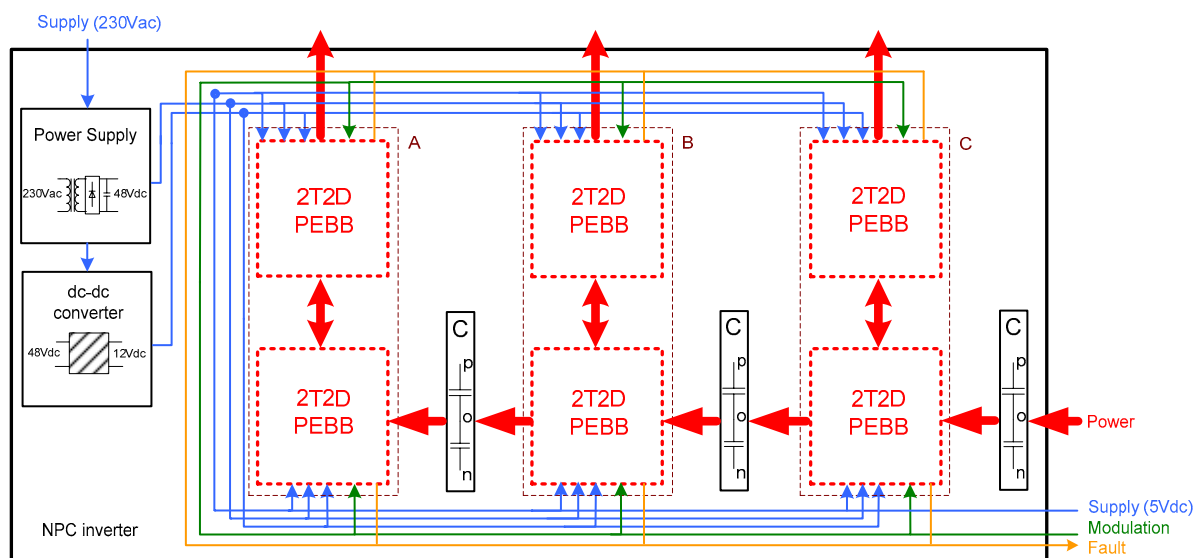


Fig. 7: Block diagram of the layout of the three-phase three-level NPC inverter

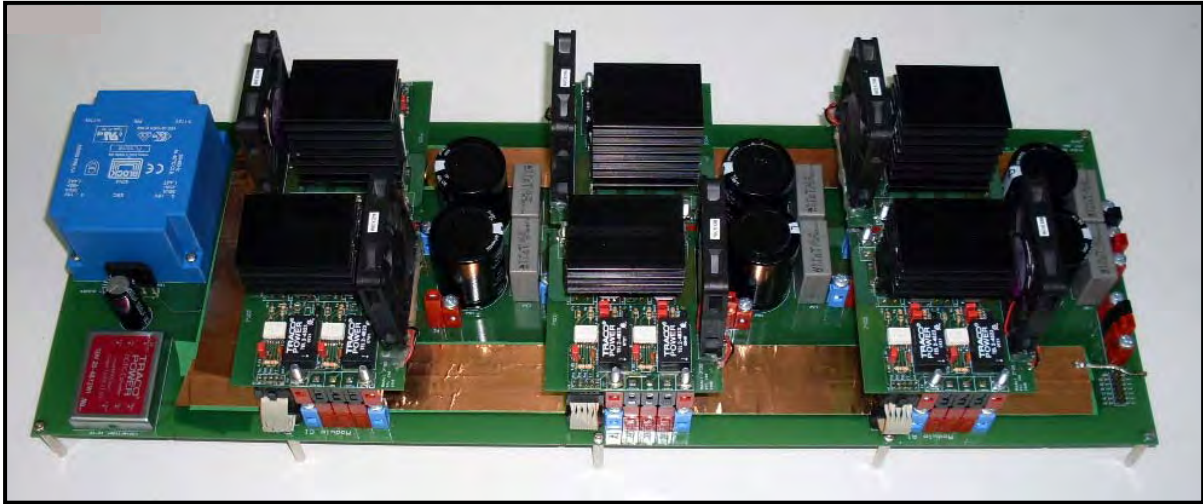


Fig. 8: Photograph of the three-phase three-level NPC inverter

As shown in Fig. 8, most parts of the converter are based on the PEBBs, so the time to build the converter is significantly reduced.

The three-phase three-level NPC inverter was tested with a Y-connected circuit of resistive loads plus an L filter, see Fig.6. The nearest three virtual space vector PWM [10] has been used to drive the inverter in open-loop, without the use of any feedback control system. Fig. 9 shows that phase-to-neutral voltages and phase currents exhibit good sinusoidal waveforms.

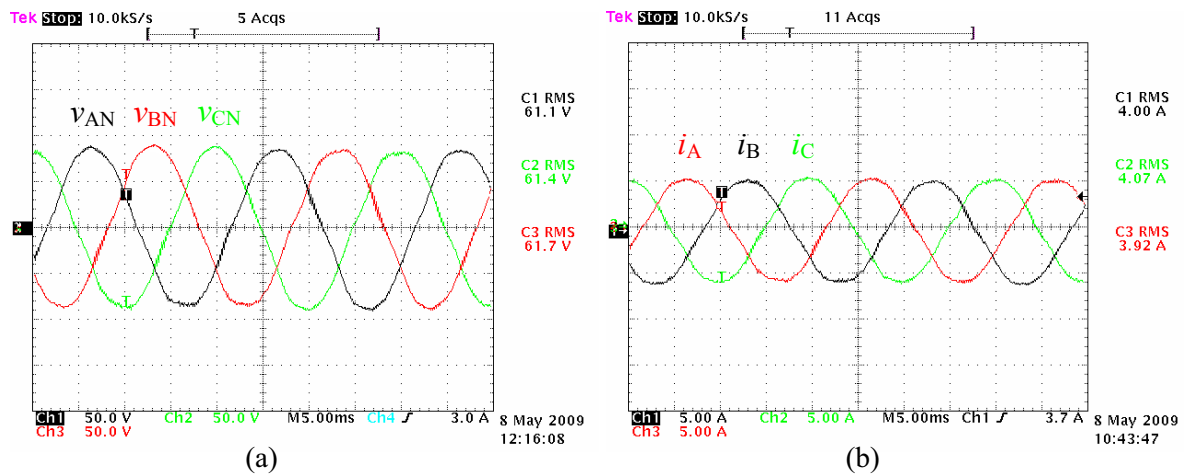


Fig. 9: Experimental results of the three-phase three-level NPC inverter tests (1). Operating conditions: $V_i=198V$, $I_i= 4,15A$, $R_{load}=16\Omega$, modulation index=0,9, $f_s=20kHz$. (a) Phase-to-neutral Voltages. (b) Phase currents

The efficiency of the converter has been calculated from the test results shown in Fig.9. As deduced from (1), the calculated efficiency (including inductor losses) is around 90%, which is an indication of good modules performance.

$$\eta_{converter} = \frac{P_{out}}{P_{in}} = \frac{\sqrt{3} \cdot \sqrt{3} \cdot 61,4V \cdot 3,99A}{198V \cdot 4,15A} = \frac{734,96W}{821,7W} \approx 0,90 \quad (1)$$

Plots of Fig. 10 show some additional results. Fig. 10 (a) shows the five levels of the NPC inverter phase-to-phase voltages; while Fig. 10 (b) proves that the output current and the output voltage are in phase (resistive load).

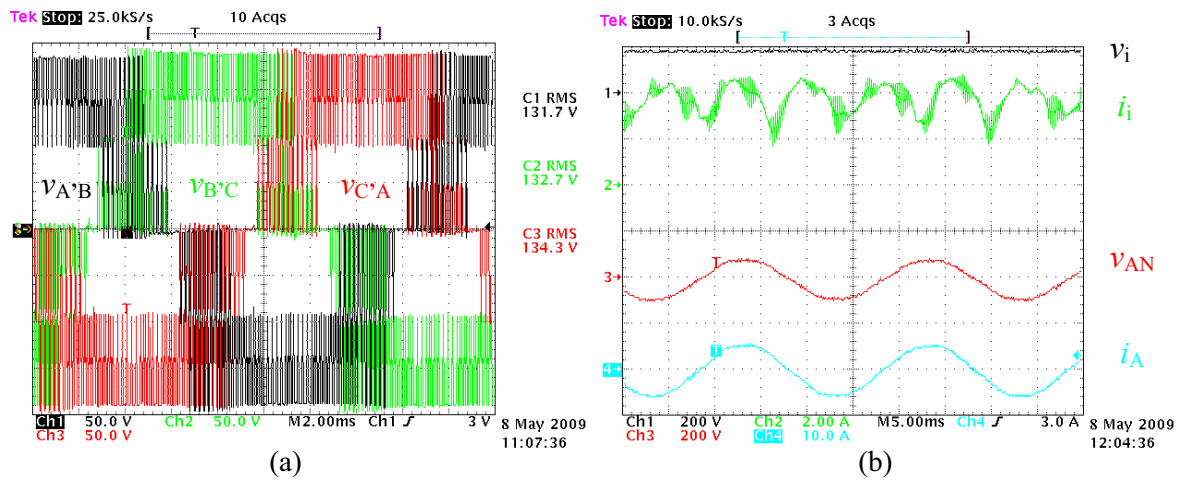


Fig. 10: Experimental results of the three-phase three-level NPC inverter tests (2). Operating conditions: $V_i=198V$, $I_i= 4,15A$, $R_{load}=16\Omega$, modulation index=0,9, $f_s=20kHz$. (a) Phase-to-phase voltages before filtering. (b) Ch.1: v_i , Ch.2: i_i , Ch.3: v_{AN} , Ch.4: i_A .

DC-DC push-pull converter

As shown in Fig.11, only one 2T2D PEBB is needed to build a push-pull converter. Extra diodes of the PEBB are not used.

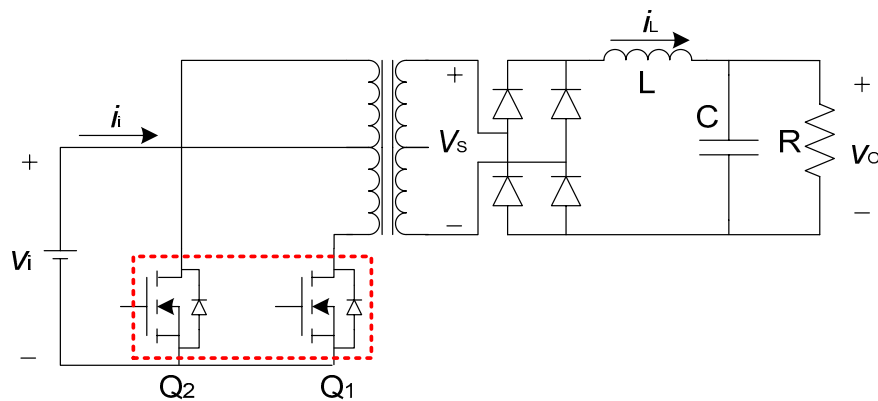


Fig. 11: dc-dc push-pull converter based on a 2T2D PEBB

Fig. 12 presents the block diagram of the layout of the push-pull converter, which includes:

- A conventional Power Supply (Transformer + bridge rectifier + capacitor) which generates 48Vdc for isolated power supplies of the PEBBs.
- A dc-dc converter which generates 12Vdc for the fans.
- A 2T2D PEBB.
- The transformer of the push-pull converter.
- A full-bridge diode rectifier.
- An LC Filter.
- Modulation, supply, fault signal and power buses.

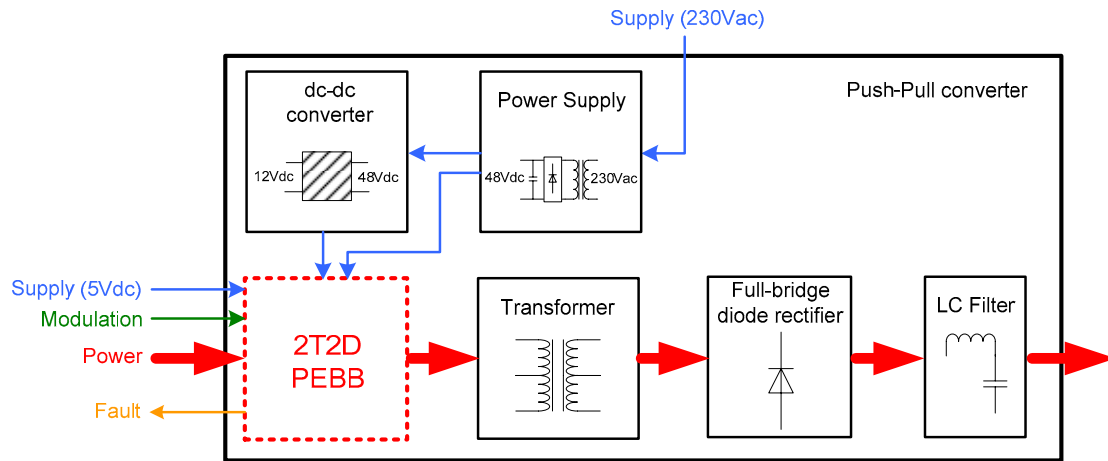


Fig. 12: Block diagram of the layout of the push-pull converter

A set up of the push-pull converter tested in this work is depicted in Fig. 13.

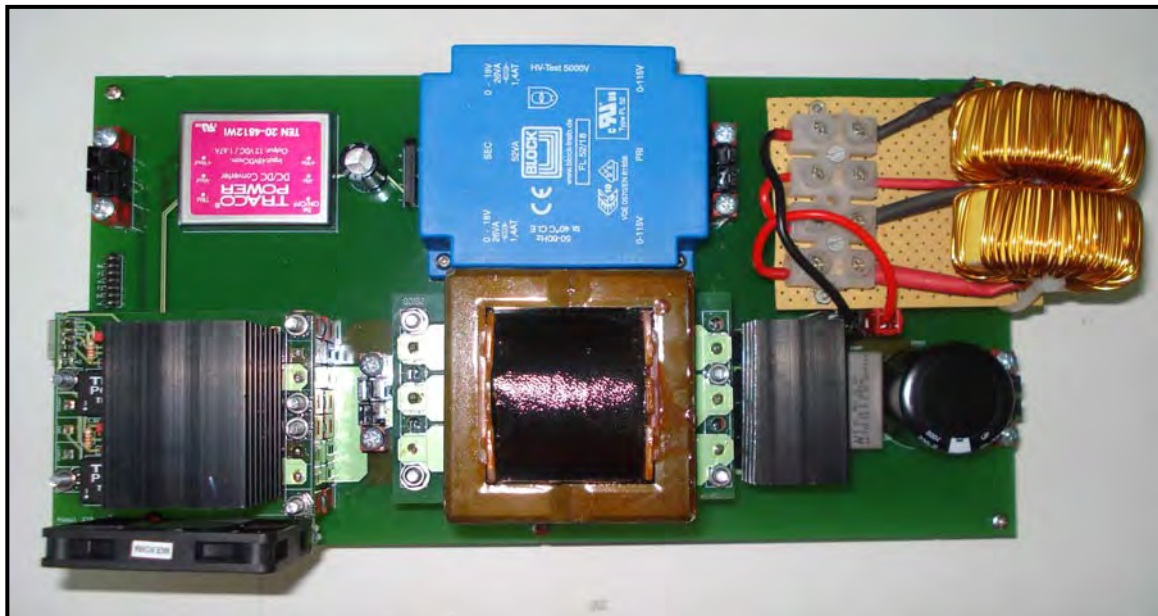


Fig. 13: Photograph of the tested push-pull converter

Fig.14 demonstrates a correct converter in open-loop operation. However, in Fig.14 (a) voltage overshoots, due to the leakage inductance of the transformer, can be observed. Snubber circuits have not been used to reduce these overshoots because the goal of these tests was to evaluate the good performance of the PEBB.

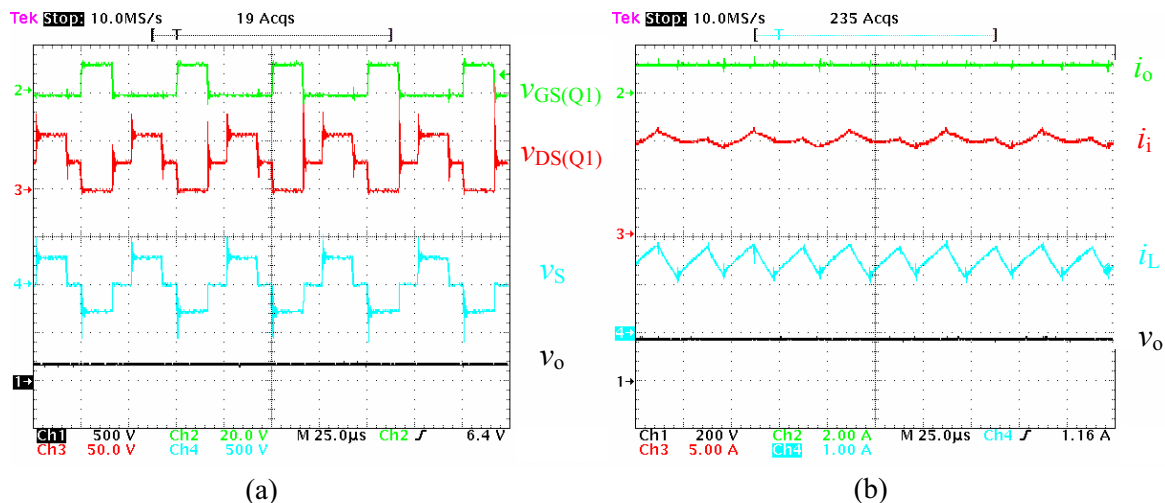


Fig. 14: Some results of the dc-dc push-pull converter tests. Operating conditions: $V_i=29,5V$, $I_i= 10A$, $R=130\Omega$, $f_s=20kHz$. (a) Ch.2(green): $v_{GS(Q1)}$, Ch.3(red): $v_{DS(Q1)}$, Ch.4(blue): v_S , Ch.1(black): v_o . (b) Ch.2(green): i_o , Ch.3(red): i_i , Ch.4(blue): i_L , Ch.1(black): v_o

Conclusion

A 2T2D PEBB has been presented in this paper. It can be used to build most relevant converter topologies. The inclusion of the two additional diodes in the design permits to improve the modularity of the proposed PEBB. This quality allows implementing NPC converters of any level and some switching cells of matrix converters.

Rapid prototyping is the main advantage of using the PEBB concept. The new PEBB design allows a fast implementation time of the converters. It is only necessary to design a motherboard where the PEBBs are interconnected. Also the cost is reduced significantly, because most of the components of the converter are already in the PEBB.

Fast replacement of damaged components is another practical aspect to be considered. If any semiconductor or any other electronic component of a PEBB is damaged, it is possible to remove this PEBB from the converter and change the PEBB with a new one. Changing only the damaged component of the PEBB is another option, which also would be more practical than using a converter without PEBBs.

The designed PEBBs have been tested in two different converter topologies. The experimental results demonstrate a fairly good performance for the intended applications.

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